ELECTRICAL
& COMPUTER
ENGINEERING

ECE-595 Network Softwarization

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5G standardization & the 3GPP

GSM, GPRS, W-CDMA, UMTS, EDGE, HSPA and LTE are technologies specified by 3GPP.

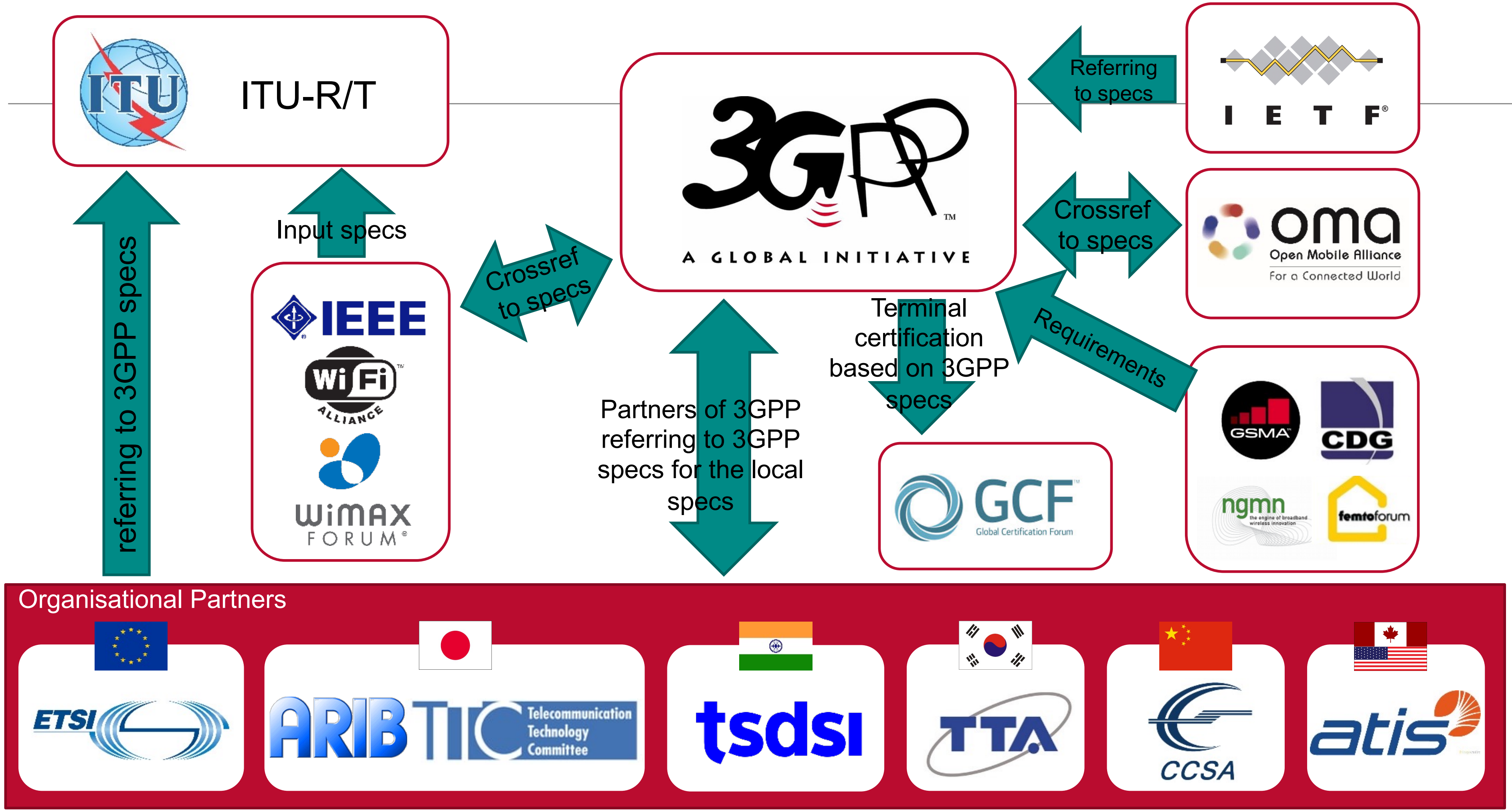
Once 3GPP specifies a technology, the specifications are used in Regional and National Standards Bodies and, finally, in ITU-R/T.

Also 5G is following the same specification evolution.

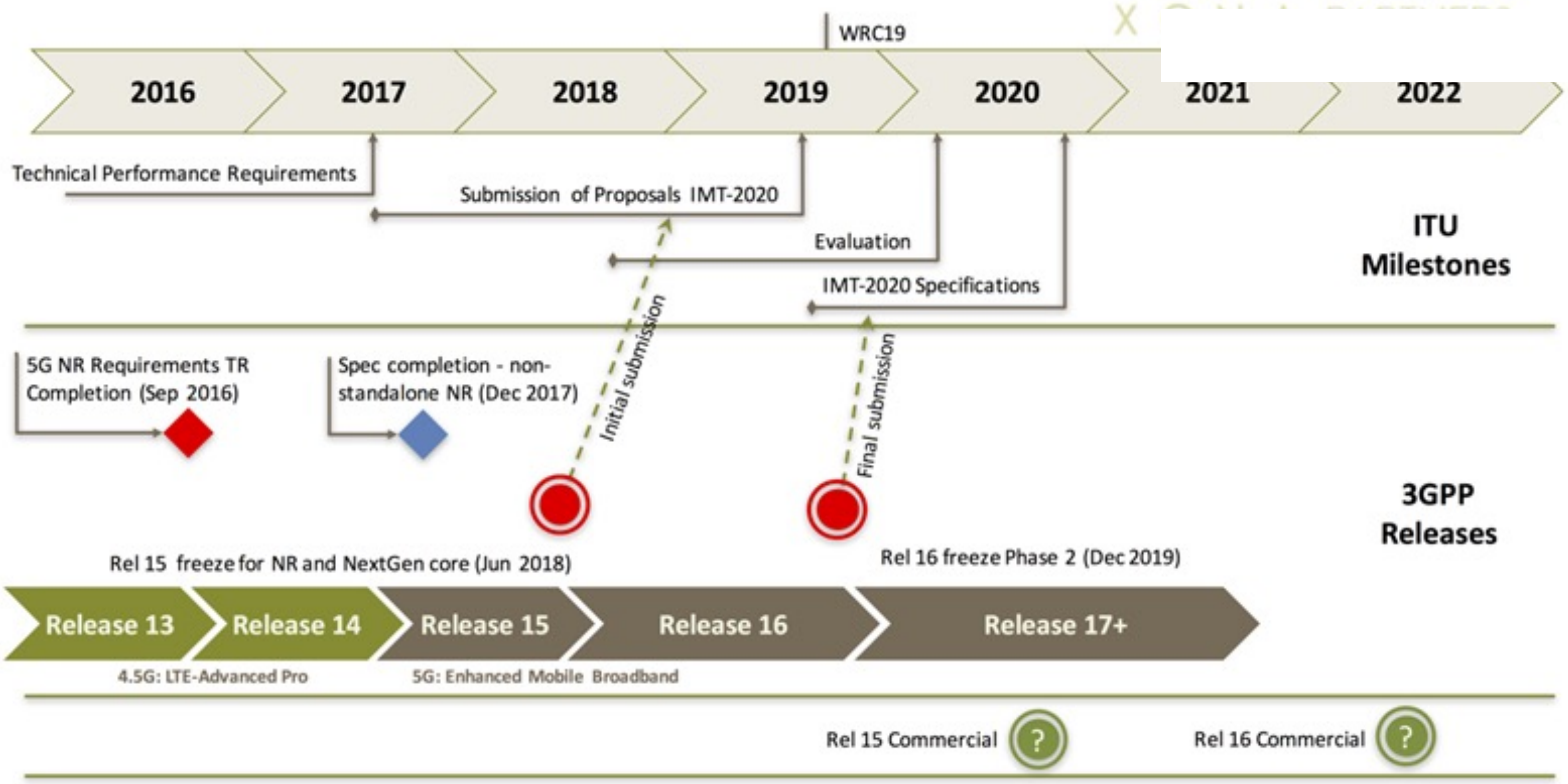
The 3GPP Organizational Partners are Regional and National Standards Bodies.

Companies participate through their membership to one of these Partners.

5G standardization & the 3GPP



Timeline of 5G in ITU-R and 3GPP Standardisation



The 5G system

The 5G System (5GS) will have three main components:

- 5G Access Network (5G-AN)
- 5G Core Network (5GC)
- User Equipment (UE)

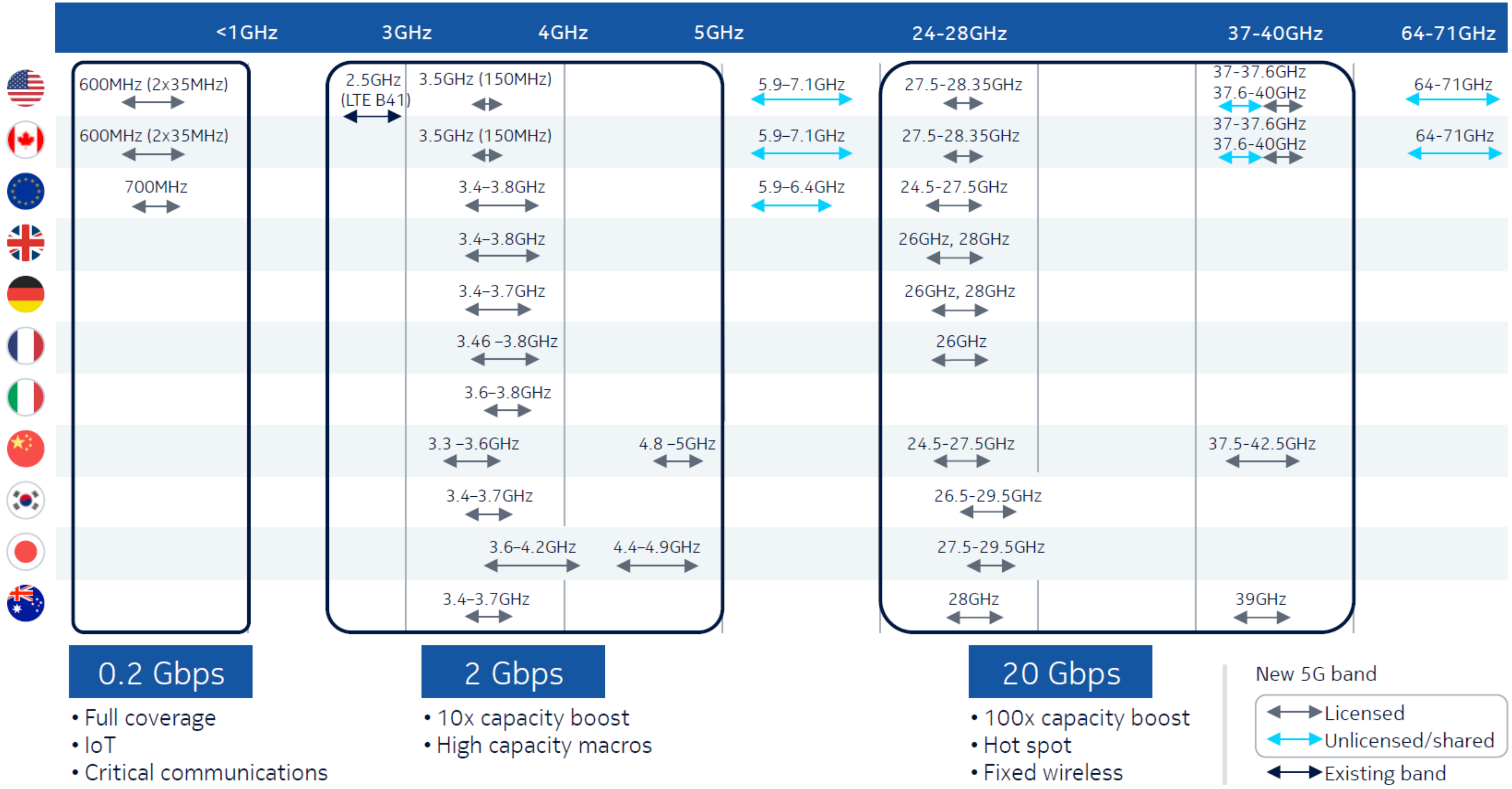
The 5GS has been specifically designed to go beyond the «**one-fits-all**» paradigm of previous mobile network technologies.

- Mobile Networks <5G has a monolithic architecture designed to support the most extreme requirements 24/7 and for all applications.

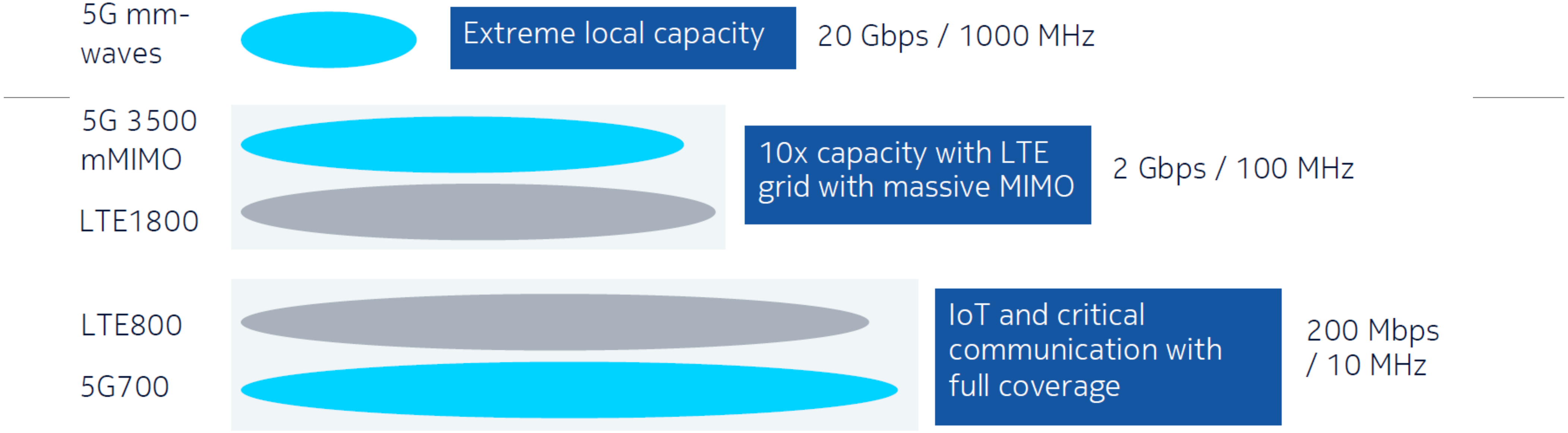
Compared to previous generations the 5GS architecture is **service based**.

That means wherever suitable the architecture elements are defined as network functions that offer their services via interfaces of a common framework to any network functions that are permitted to make use of these provided services.

The 5G Spectrum



The 5G Spectrum



5G is the first radio system designed to support any spectrum between 400 MHz and 90 GHz.

Combination of high capacity, high data rates, ubiquitous coverage and ultra-high reliability.

Low bands below 6 GHz are useful for wide area coverage and data rates up to a few Gbps.

Reliable coverage is an important factor in providing connectivity for IoT devices and for critical communication such as remote control or automotive communication.

5G can also be deployed on shared spectrum, such as the 3.5 GHz band in the USA and in unlicensed spectrum, like 5 GHz.

- New possibilities for enterprises and industries to benefit from 5G technology without the need for licensed spectrum.

New Generation Radio Access Network (NG-RAN)

The Xn interface is very similar to the LTE X2 protocol and it is used for: mobility (i.e. handover), multi-connectivity, and SON (Self Optimized Networks)

The NG-RAN represents the newly defined radio access network for 5G.

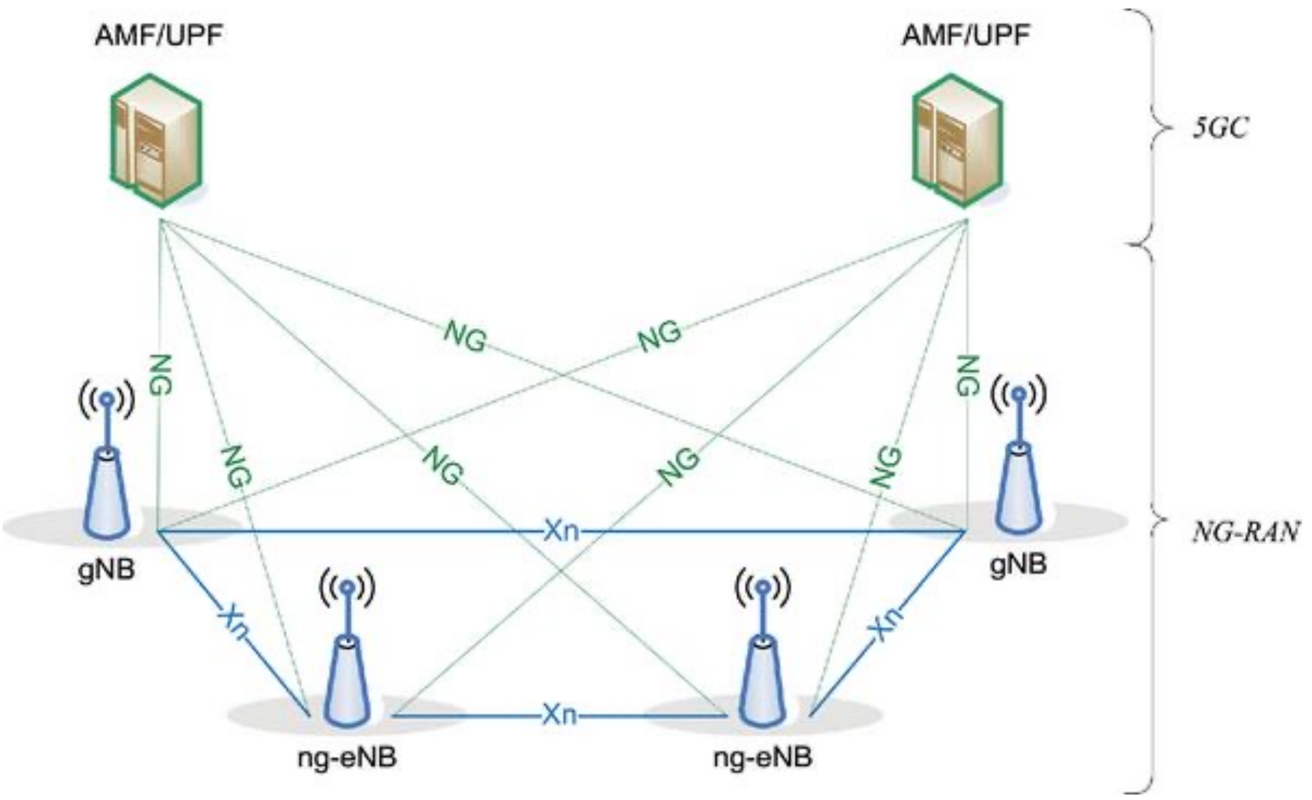
NG-RAN provides both NR and LTE radio access.

An NG-RAN node (i.e. base station) is either:

- a gNB (i.e. a 5G base station), providing NR user plane and control plane services;
- an ng-eNB, providing LTE/E-UTRAN services towards the UE.

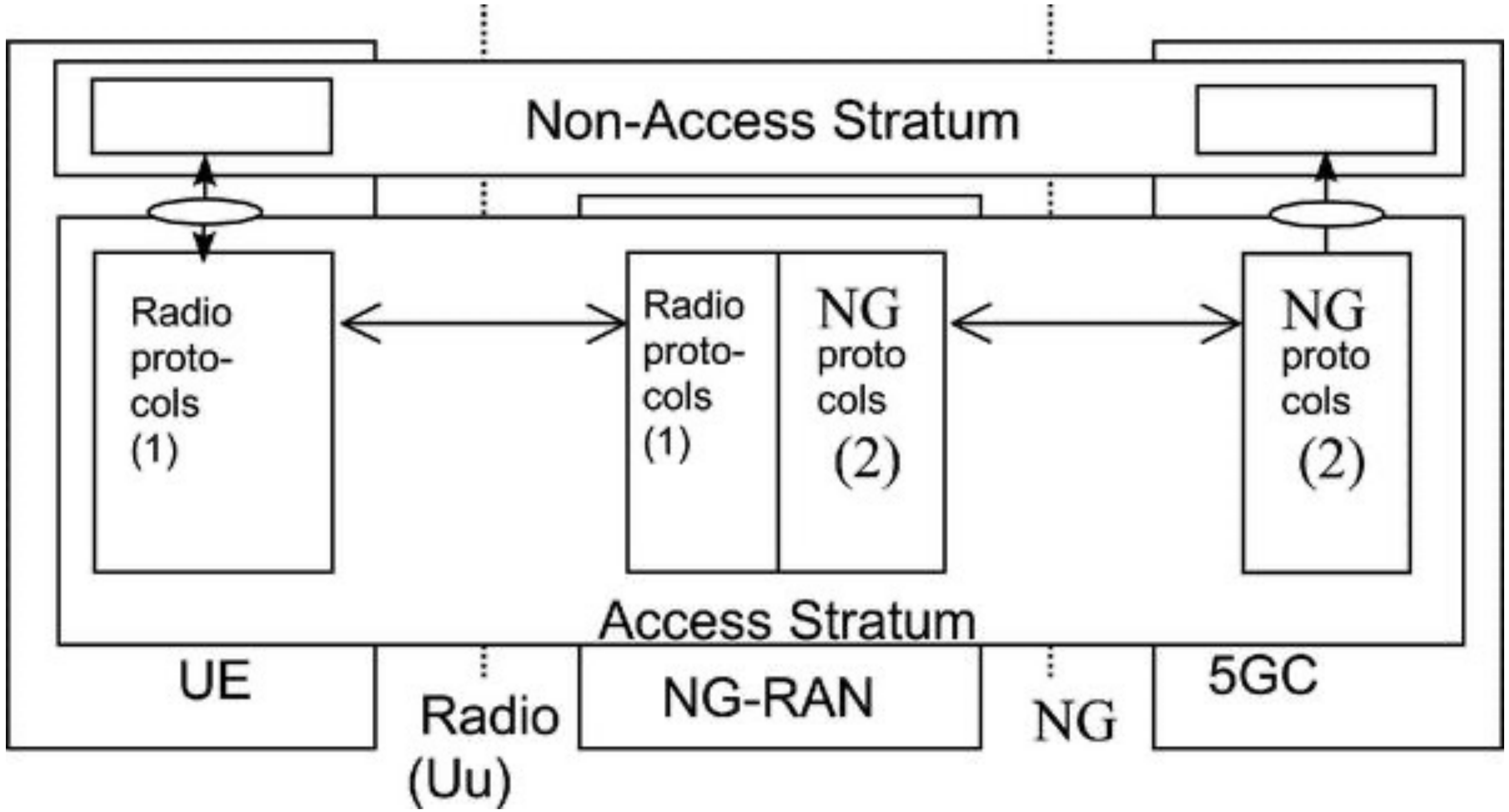
The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface.

The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5G Core (5GC).

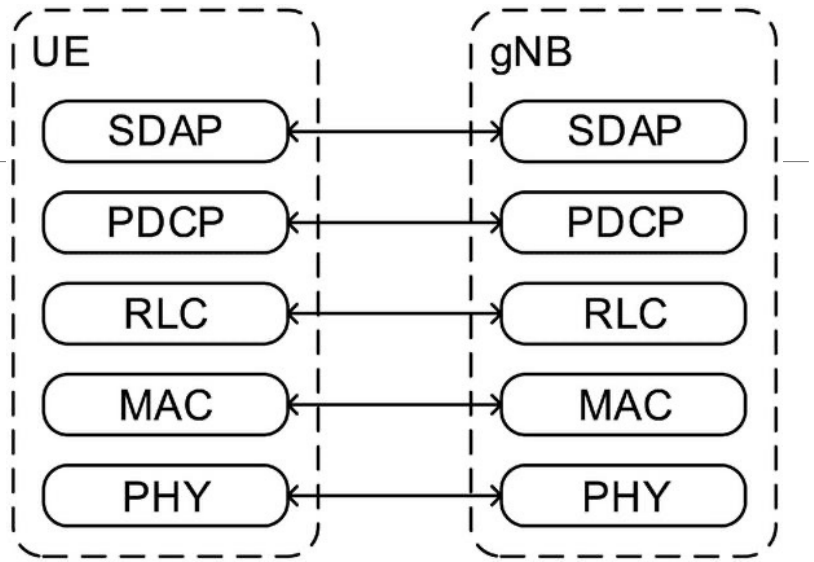


NG-RAN Protocol Stack

Similar to the protocol stack used by LTE



NG-RAN User Plane Protocol Stack



Service data adaptation protocol (SDAP):

- notable difference with respect to LTE
- It aims to support the new flow based QoS model of the 5G core network.
  - different QoS requirements for different IP flows of a PDU session.
  - mapping of IP flows with different QoS requirements to radio bearers.

Packet data convergence protocol (PDCP):

- Similarly to LTE:
  - Header compression and decompression;
  - Security functions.
- In addition to LTE:
  - data duplication over different transmission paths for URLLC (Ultra Reliable Low Latency) applications;
  - Integrity protection for user plane data.

- **Radio link control protocol (RLC)**
  - Very similar to the LTE RLC.
  - It aims to provide segmentation, in order to match the transmitted PDU size to the available radio resources, and error correction through ARQ.
- **Medium access control (MAC):**
  - Very similar to the LTE MAC
  - Multiplexing of data among different radio bearers.

RAN Splitting

The 4G RAN architecture was based on a “monolithic” building block, the eNB.

Since the earliest phases of the NR study, however, it was felt that splitting up the gNB (the NR logical node) between Central Units (CUs) and Distributed Units (DUs) would bring additional benefits:

- A flexible hardware implementation allows scalable cost-effective solutions.
- A split architecture allows coordination of performance features, load management and real-time performance optimization.
- It also enables virtualized deployments.

Configurable functional splits enable adaptation to various use cases, such as variable transport latency.

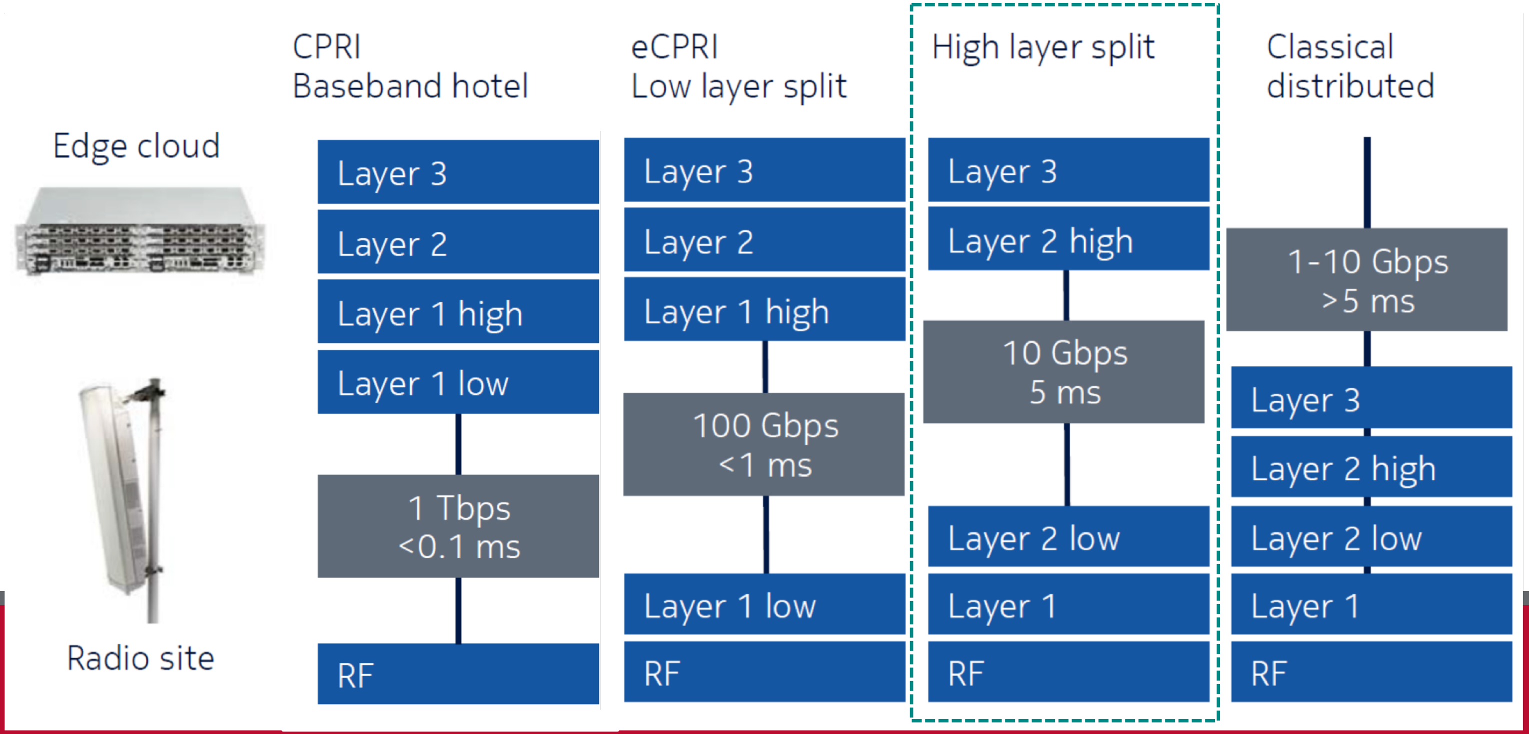
The choice of how to split NR functions in the architecture depends on radio network deployment scenarios, constraints and envisaged services.

Several possible CU-DU split options have been considered, and 3GPP decided to adopt the “**High Level Split**” as base of specifications.

Open Radio Access Network (ORAN)

The 5G radio network includes new interfaces between the radio unit and baseband unit or edge cloud unit, with the aim of bringing more flexibility to the radio network deployment.

Open interfaces in the radio network are supported by the ORAN Alliance.



High Level Split (HLS)

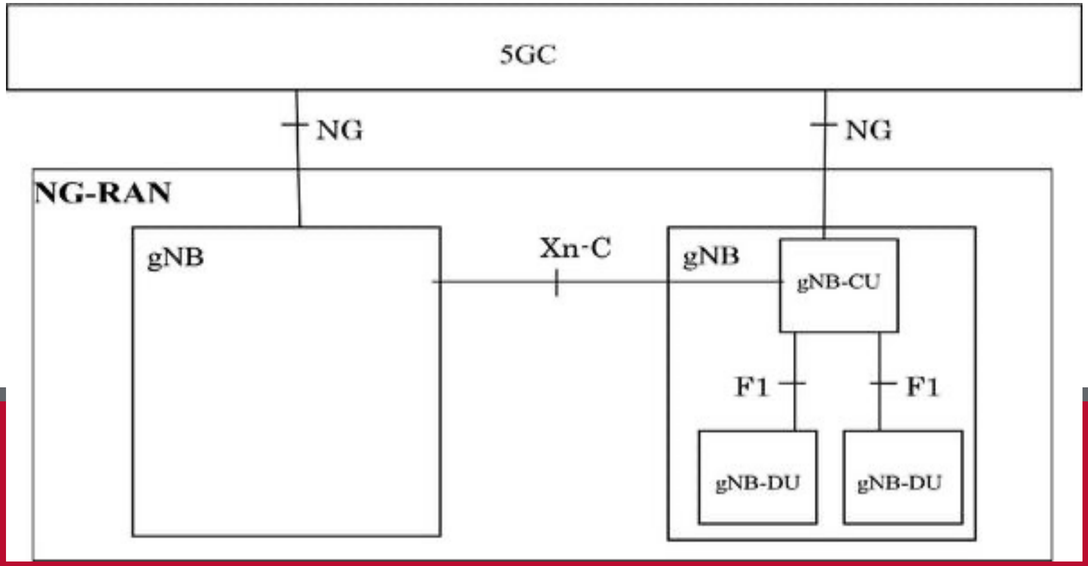
A gNB may then consist of a gNB-CU and one or more gNB-DU(s).

The interface between gNB-CU and gNB-DU is called F1.

The NG and Xn-C interfaces for a gNB terminate in the gNB-CU.

One gNB-DU may support one or more cells.

The internal structure of the gNB is not visible to the core network and other RAN nodes, so the gNB-CU and connected gNB-DUs are only visible to other gNBs and the 5GC as a gNB.



High Level Split (HLS)

The F1 interface :

- supports signaling exchange and data transmission between the endpoints,
- separates Radio Network Layer and Transport Network Layer,
- enables the exchange of UE-associated and non-UE-associated signaling.

The F1 interface functions are divided into:

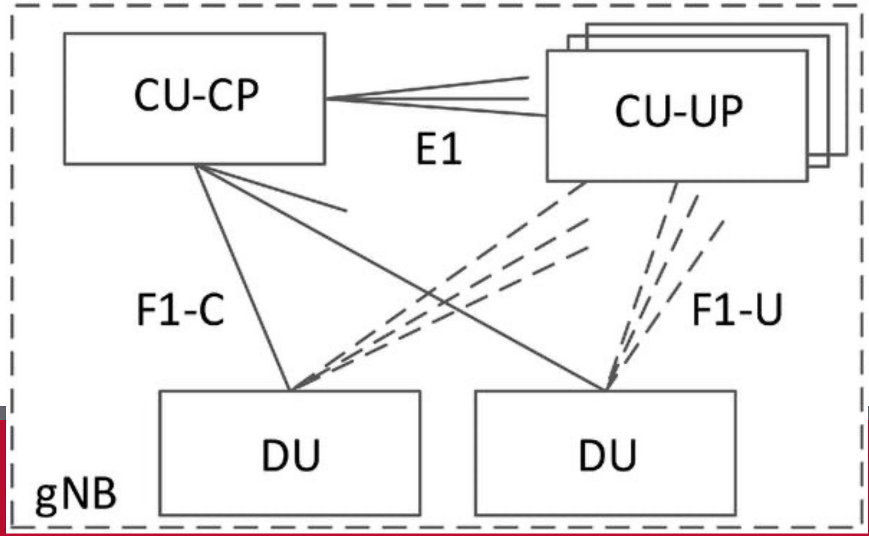
- F1-C (control-plane) functions: F1 Interface Management, System Information Management Functions, F1 UE Context Management Functions, RRC Message Transfer Function.
- F1-U (user-plane) functions: Transfer of User Data, Flow Control Function (including management of the mobility among different DUs of the same CU).

High Level Split (HLS)

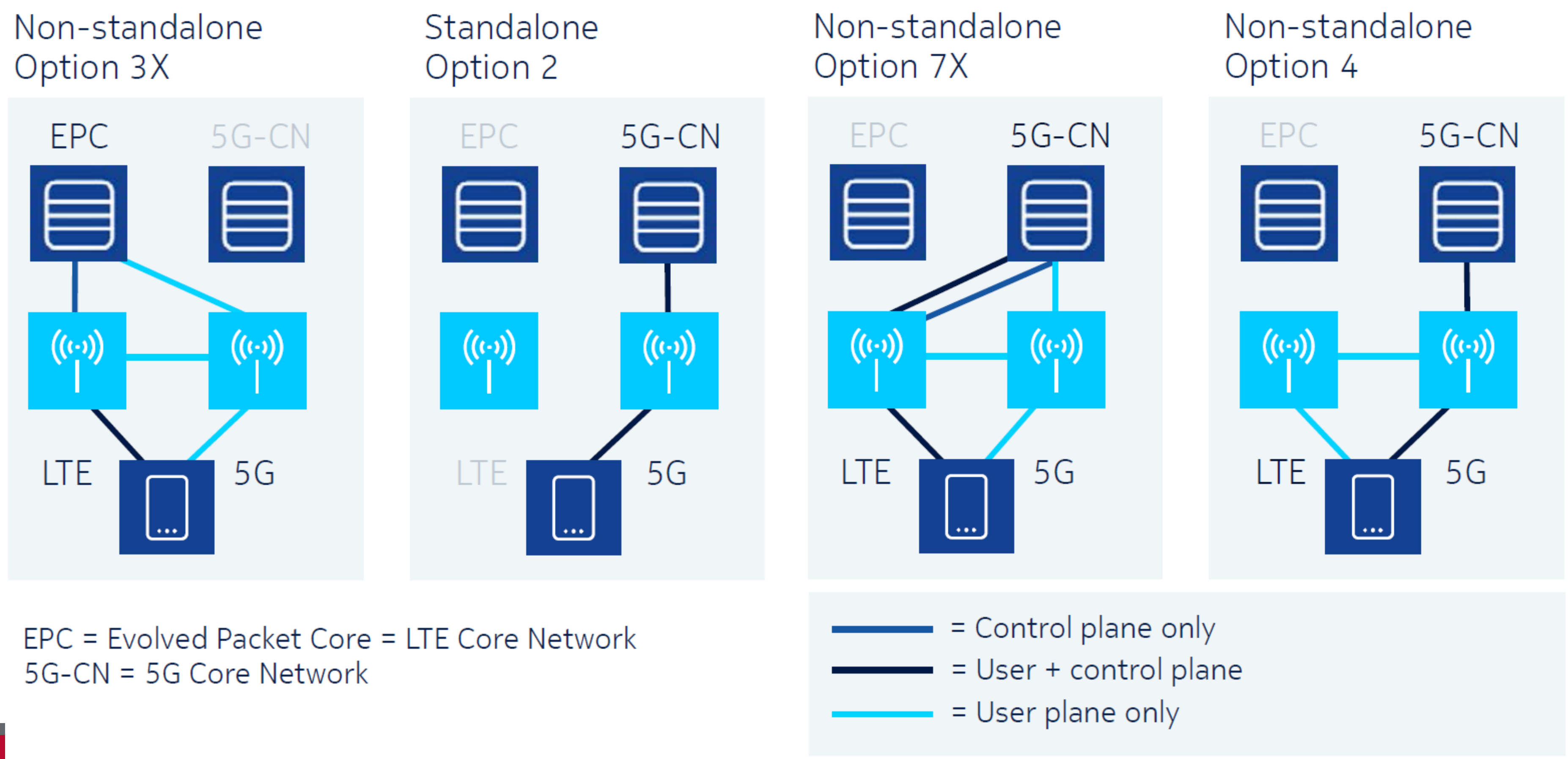
The gNB-CU can be further separated into its CP and UP parts:

- The **gNB-CU-CP**: it hosts the RRC and the control plane part of the PDCP protocol; it also terminates the E1 interface connected with the gNB-CU-UP and the F1-C interface connected with the gNB-DU
- The **gNB-CU-UP**: it hosts the user plane part of the PDCP protocol and the SDAP protocol. The gNB-CU-UP terminates the E1 interface connected with the gNB-CU-CP and the F1-U interface connected with the gNB-DU.

The interface between CU-CP and CU-UP is called E1.



4G-5G Interworking



EPC = Evolved Packet Core = LTE Core Network
5G-CN = 5G Core Network

The 5G Core Architecture Model

The 5G System architecture is defined to support data connectivity and services enabling deployments to use techniques such as NFV and SDN.

The 5G architecture is defined as service-based and the interaction between network functions is represented in two ways.

- A **service-based representation**, where Network Functions (NFs) within the Control Plane (CP) enable other authorized network functions to access their services.
- A **reference point representation** shows the existing interaction between the NF services in the network functions described by point-to-point reference point between any two network functions.

Network functions within the 5G Core Network Control Plane shall only use service-based interfaces for their interactions.

The 5G Core Architecture Model

Some key principles and concept at the foundations of the **5G Service-based Architecture** (SBA) are to:

- Separate the User Plane (UP) functions from the Control Plane (CP) functions, allowing independent scalability, evolution and flexible deployments
  - e.g. centralized location or distributed (remote) location.
- Modularize the function design, e.g. to enable flexible and efficient network slicing.
- Wherever applicable, define procedures (i.e. the set of interactions between network functions) as services, so that their re-use is possible.
- Enable each Network Function to interact with other NF directly if required.

The 5G Core Architecture Model

Minimize dependencies between the Access Network (AN) and the Core Network (CN).

- The architecture is defined with a converged core network with a common AN - CN interface which integrates different Access Types (e.g. 3GPP and non-3GPP access).

Support a unified authentication framework.

Support "stateless" NFs, where the "compute" resource is decoupled from the "storage" resource.

Support capability exposure.

Support concurrent access to local and centralized services.

- To support low latency services and access to local data networks, UP functions can be deployed close to the Access Network.

Support roaming with both Home routed traffic as well as Local breakout traffic in the visited Public Land Mobile Network (PLMN).

The 5G Common API Framework (CAPIF)

3GPP took the forward-looking decision to use RESTful APIs not only for 3rd party functionality exposure but also for via the SBIs.

Therefore, the 5G Core Network internal communication obeys the same principles as the functional exposure, thus allowing a harmonized and holistic technological approach of the complete 5G system, fully in-line with the progressive paradigms which are at the heart of a wide range of services used by end-customers as well as for the automation of whole industries.

The 3GPP CT4 Working Group came up with 3GPP TS 29.50 which states guidelines for API creation within 3GPP.

These guidelines are now not only used for northbound APIs and SBA but will also be used for e.g. the orchestration APIs.

Other 5G functions are expected to be aligned to these principles during upcoming 3GPP releases.

Restful APIs

Roy Fielding described what he called the REST architectural style in his dissertation (in the year 2000).

REST stands for *REpresentational State Transfer* and is not a protocol or description language, it is also not a specific architecture.

It is usually described as a set of principles or paradigm.

Whilst this view is correct, the term RESTful is nowadays used not only for the related principles themselves but also for deployed applications and software environments following these principles.

In chapter 6 of his dissertation Fielding describes in detail how the principles of REST can be used within the World Wide Web, i.e. by making use of Uniform Resource Indicators (URIs), the Hypertext Transfer Protocol (HTTP), different data description languages and how such technologies can be used in a "RESTful" way for real world deployments.

In the 18 years since the publication of Fielding's dissertation, the REST paradigm has fundamentally re-shaped the way how software applications are designed, implemented and deployed. It is used throughout the IT industry, there exist countless tools as well as books, articles and web pages to support its use and a huge developer community is experienced with REST principles.

REST has proven to be a reliable and future proof way for developing distributed applications.

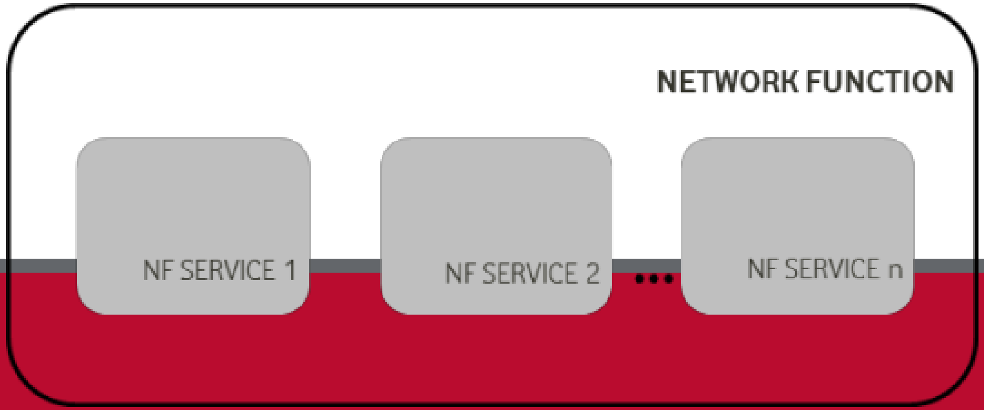
Network Function Services

An NF service is meant to offer a capability to authorised consumers.

Network Functions may offer different capabilities and thus, different NF services to distinct consumers.

Each of the NF services offered by a Network Function shall be self-contained, reusable and use management schemes independently of other NF services offered by the same Network Function (e.g. for scaling, healing, etc).

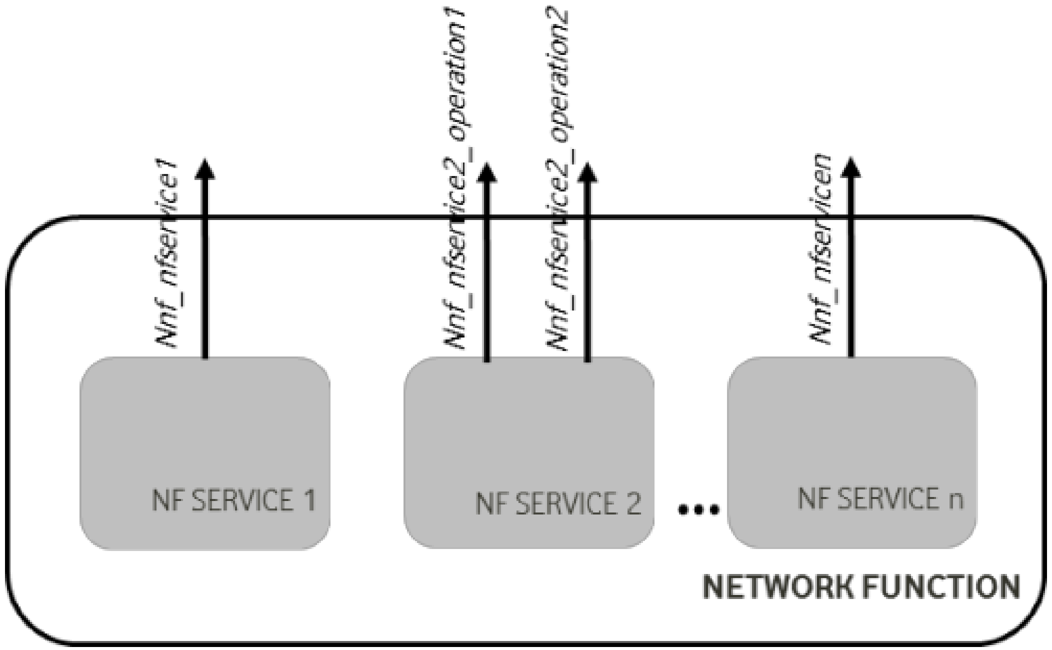
Even if there can be dependencies between NF services within the same Network Function due to sharing some common resources, e.g. context data, NF services offered by a single Network Function are managed independently of each other.



Network Function Services

Each NF service shall be accessible by means of an interface.

An interface may consist of one or several operations.



Network Function Service Framework

An NF service is one type of capability exposed by an NF (NF Service Producer) to other authorized NF (NF Service Consumer) through a service-based interface.

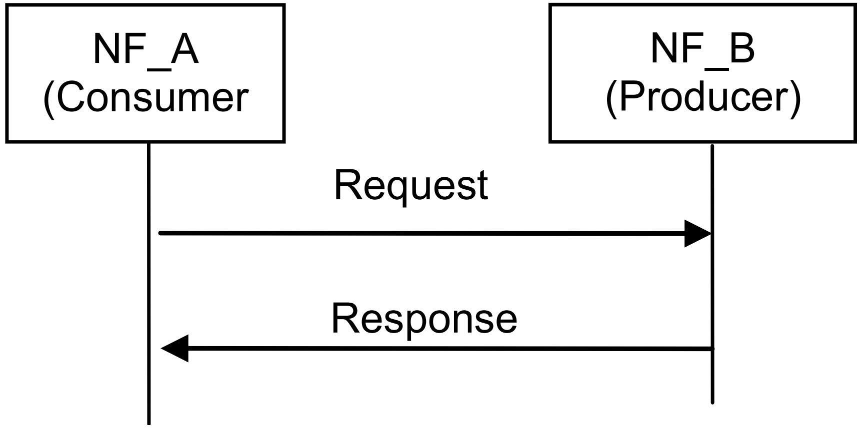
Following are criteria for specifying NF services:

- NF services are derived from the system procedures that describe end-to-end functionality, where applicable.
- System procedures can be described by a sequence of NF service invocations.

Network Function Service Framework

The interaction between two Network Functions (Consumer and Producer) within this NF service framework follows two mechanisms:

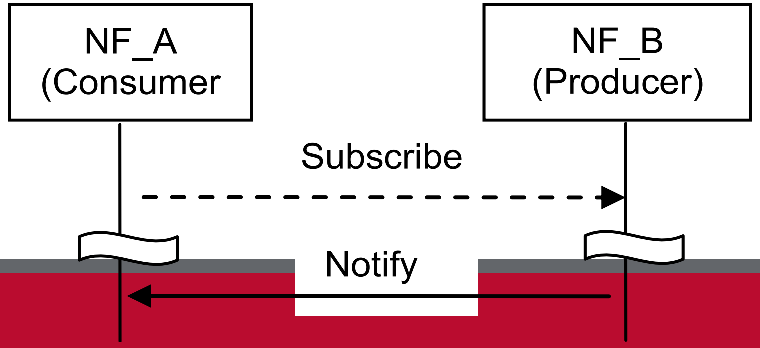
- "**Request-response**":
  - A Control Plane NF_B (NF Service Producer) is requested by another Control Plane NF_A (NF Service Consumer) to provide a certain NF service.
  - NF_B provides an NF service based on the request by NF_A.



Network Function Service Framework

"Subscribe-Notify":

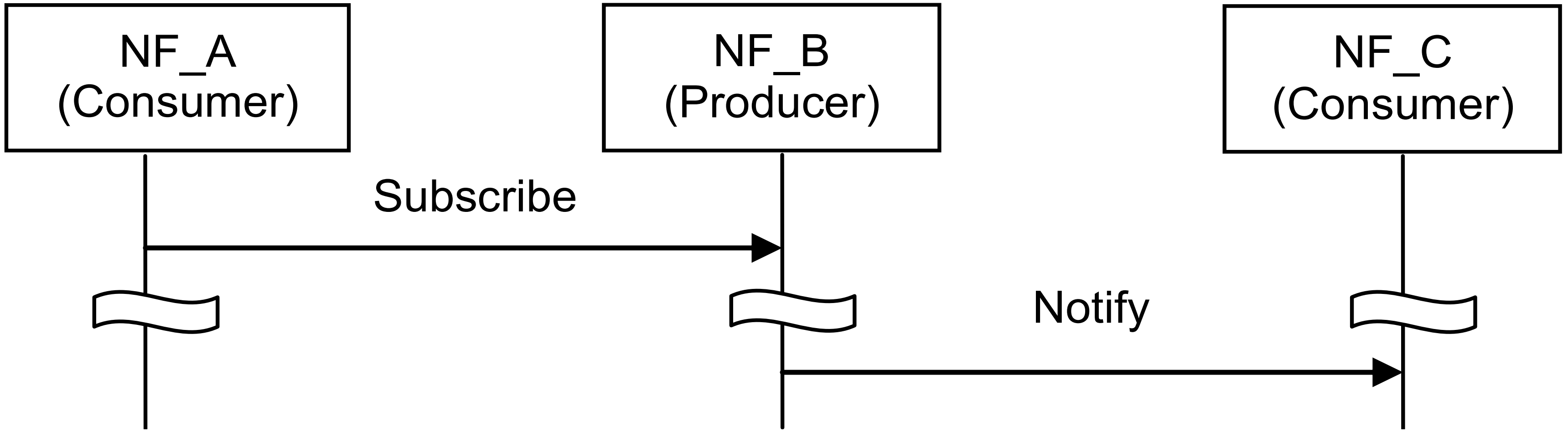
- A Control Plane NF_A (NF Service Consumer) subscribes to NF Service offered by another Control Plane NF_B (NF Service Producer).
- Multiple Control Plane NFs may subscribe to the same Control Plane NF Service.
- NF_B notifies the results of this NF service to the interested NF(s) that subscribed to this NF service.
- The subscription request:
  - shall include the notification endpoint (e.g. the notification URL) of the NF Service Consumer to which the event notification from the NF Service Producer should be sent to.
  - may include notification request for periodic updates or notification triggered through certain events (e.g., the information requested gets changed, reaches certain threshold etc.).



Network Function Service Framework

A Control Plane NF_A may also subscribe to NF Service offered by Control Plane NF_B on behalf of Control Plane NF_C.

In this case, NF_A includes the notification endpoint of the NF_C in the subscription request.



Network Function Service discovery

A Control Plane Network function (NF) within the 5G Core network may expose its capabilities as services via its service based interface, which can be re-used by Control Plane CN NFs.

The NF service discovery enables a CN NFs to discover NF instance(s) that provide the expected NF service(s). The NF service discovery is implemented via the NF discovery functionality.

Network Function Service Authorization

NF service authorization shall ensure the NF Service Consumer is authorized to access the NF service provided by the NF Service Provider.

Service authorization information shall be configured as one of the components in NF profile of the NF Service Producer.

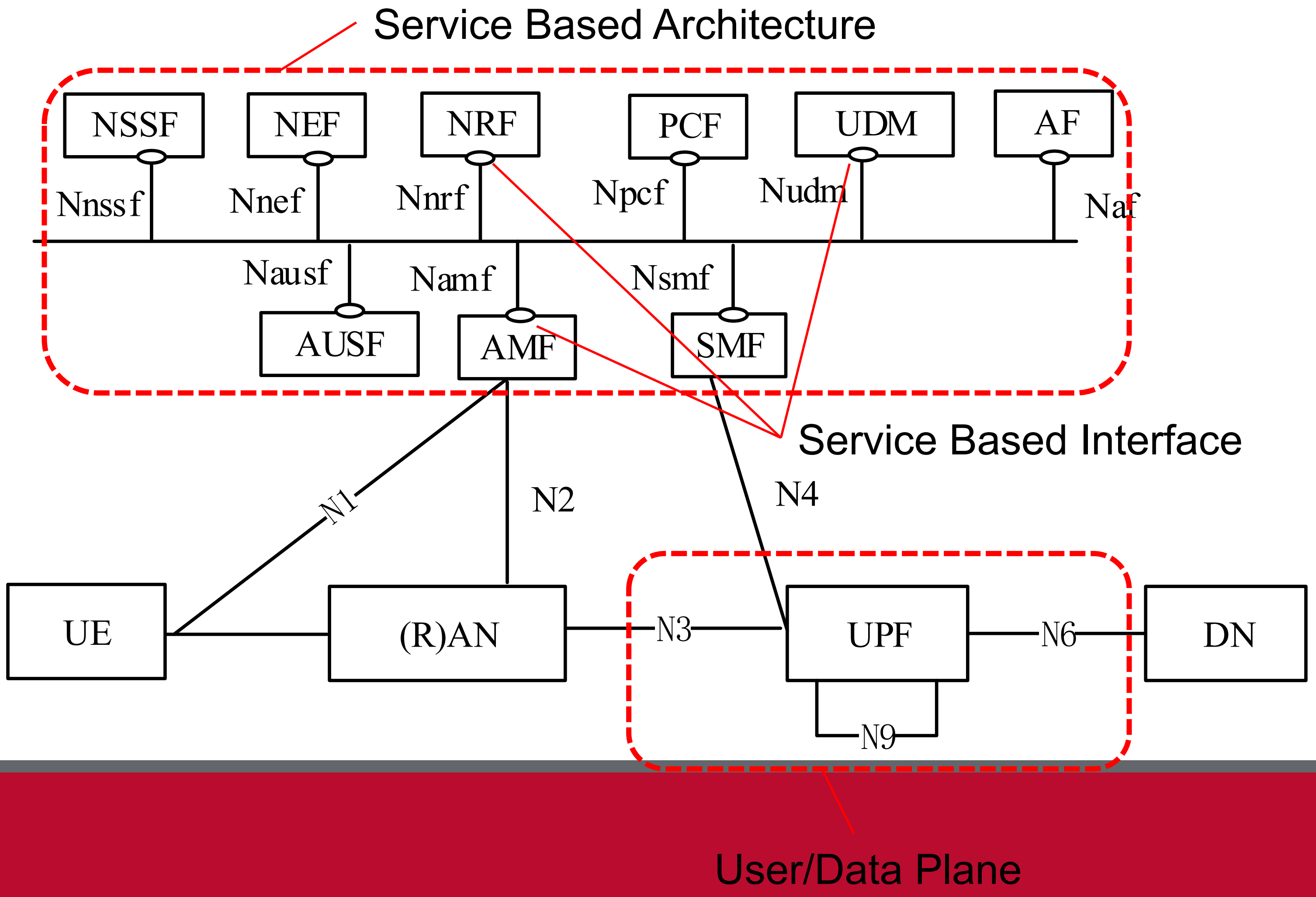
- It shall include the NF type (s) and NF realms/origins allowed to consume NF Service(s) of NF Service Producer.

Due to roaming agreements and operator policies, a NF Service Consumer shall be authorised based on UE/subscriber/roaming information and NF type,

The Service authorization may entail two steps:

- Check whether the NF Service Consumer is permitted to discover the requested NF Service Producer instance during the NF service discovery procedure.
- Check whether the NF Service Consumer is permitted to access the requested NF Service Producer for consuming the NF service, with a request type granularity.

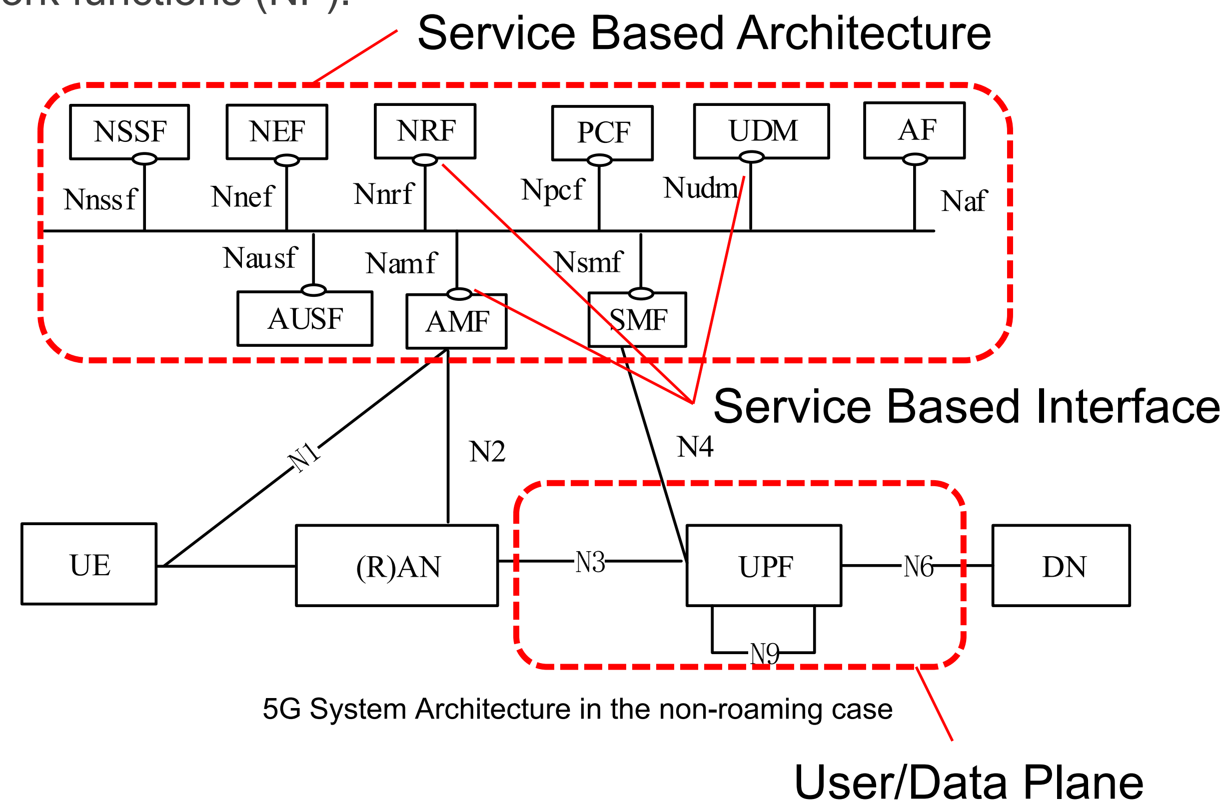
The 5G Service-based Architecture



The 5G Service-based Architecture

The 5G System architecture consists of the following network functions (NF).

- Authentication Server Function (AUSF)
- Access and Mobility Management Function (AMF)
- Unstructured Data Storage Function (UDSF)
- Network Exposure Function (NEF)
- Network Repository Function (NRF)
- Network Slice Selection Function (NSSF)
- Policy Control Function (PCF)
- Session Management Function (SMF)
- Unified Data Management (UDM)
- Unified Data Repository (UDR)
- User Plane Function (UPF)
- Application Function (AF)
- User Equipment (UE)
- (Radio) Access Network ((R)AN)
- 5G-Equipment Identity Register (5G-EIR)
- Security Edge Protection Proxy (SEPP)
- Network Data Analytics Function (NWDAF)



5G System Architecture in the non-roaming case

The 5G Service-based Architecture

2-4G:

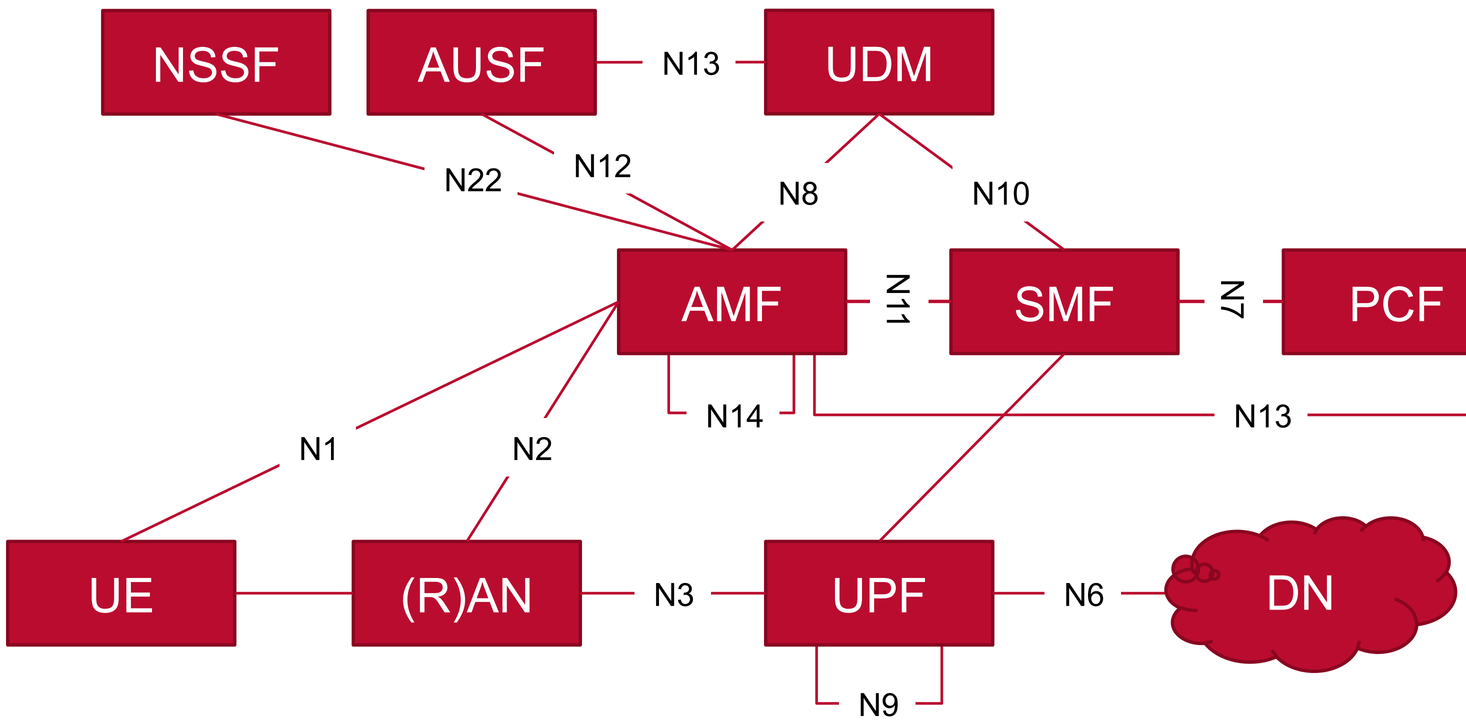
- Functional entities
- Single Core
- Dedicated Protocols

5G

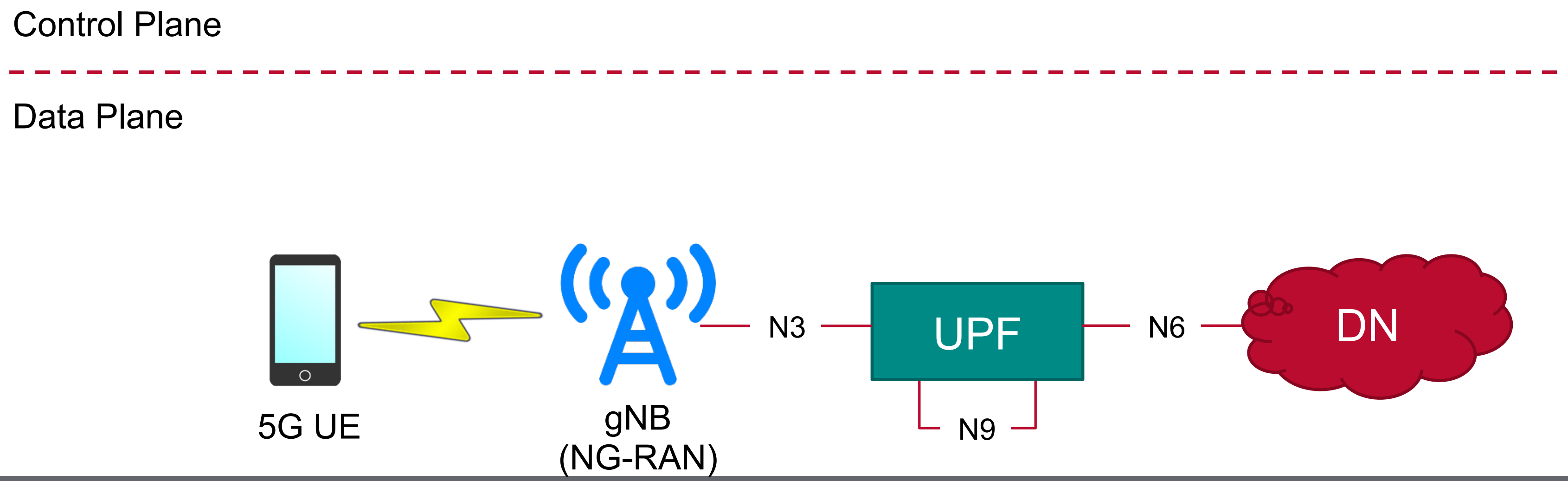
5G

- Service Based
- Virtualization and Slicing
- Softwarization
- Application Programming Interfaces
- Harmonized Protocols (HTTP/RESTfull)
- Exposure to 3rd parties
- Backward and Forward Compatibility

The 5G Service-based Architecture: reference Point Representation



5G NF Operations



The User plane function (UPF)

UPF provides user-plane functionalities similar to the ones of S/P-GW in 4G.

The UPF includes the following functionality.

- Anchor point for Intra-/Inter-RAT mobility (when applicable).
- External PDU Session point of interconnect to Data Network.
- Packet routing & forwarding (e.g. support of Uplink classifier to route traffic flows to an instance of a data network, support of Branching point to support multi-homed PDU Session).
- Packet inspection (e.g. Application detection based on service data flow template and the optional PFDs received from the SMF in addition).
- User Plane part of policy rule enforcement, e.g. Gating, Redirection, Traffic steering).
- Lawful intercept (UP collection).
- Traffic usage reporting.

The User plane function (UPF)

Traffic usage reporting.

QoS handling for user plane, e.g. UL/DL rate enforcement, Reflective QoS marking in DL.

Uplink Traffic verification (SDF to QoS Flow mapping).

Transport level packet marking in the uplink and downlink.

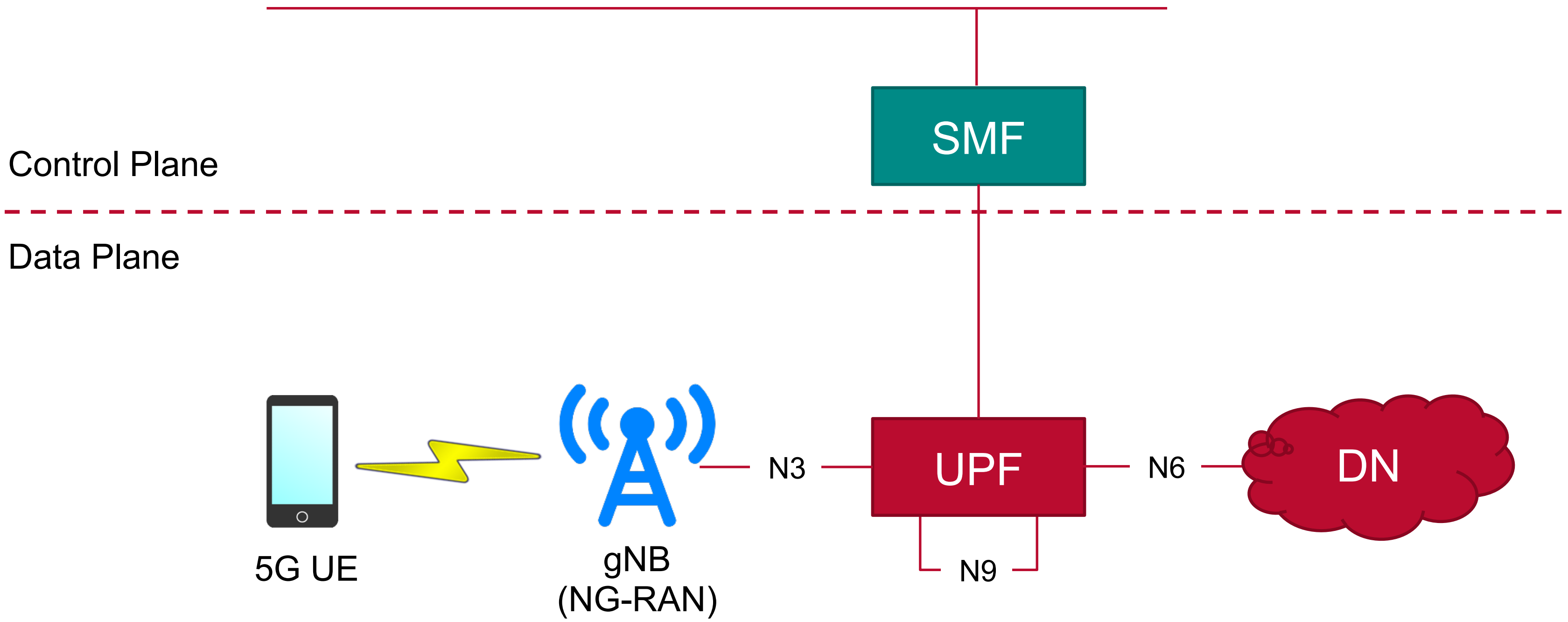
Downlink packet buffering and downlink data notification triggering.

Sending and forwarding of one or more "end marker" to the source NG-RAN node.

ARP proxying and / or IPv6 Neighbour Solicitation Proxying functionality for the Ethernet PDUs.

- The UPF responds to the ARP and / or the IPv6 Neighbour Solicitation Request by providing the MAC address corresponding to the IP address sent in the request.

5G NF Operations



The Session Management function (SMF)

Multiple SMFs (one per each slice) can be associated to the same UE.

The SMF includes the following functionality:

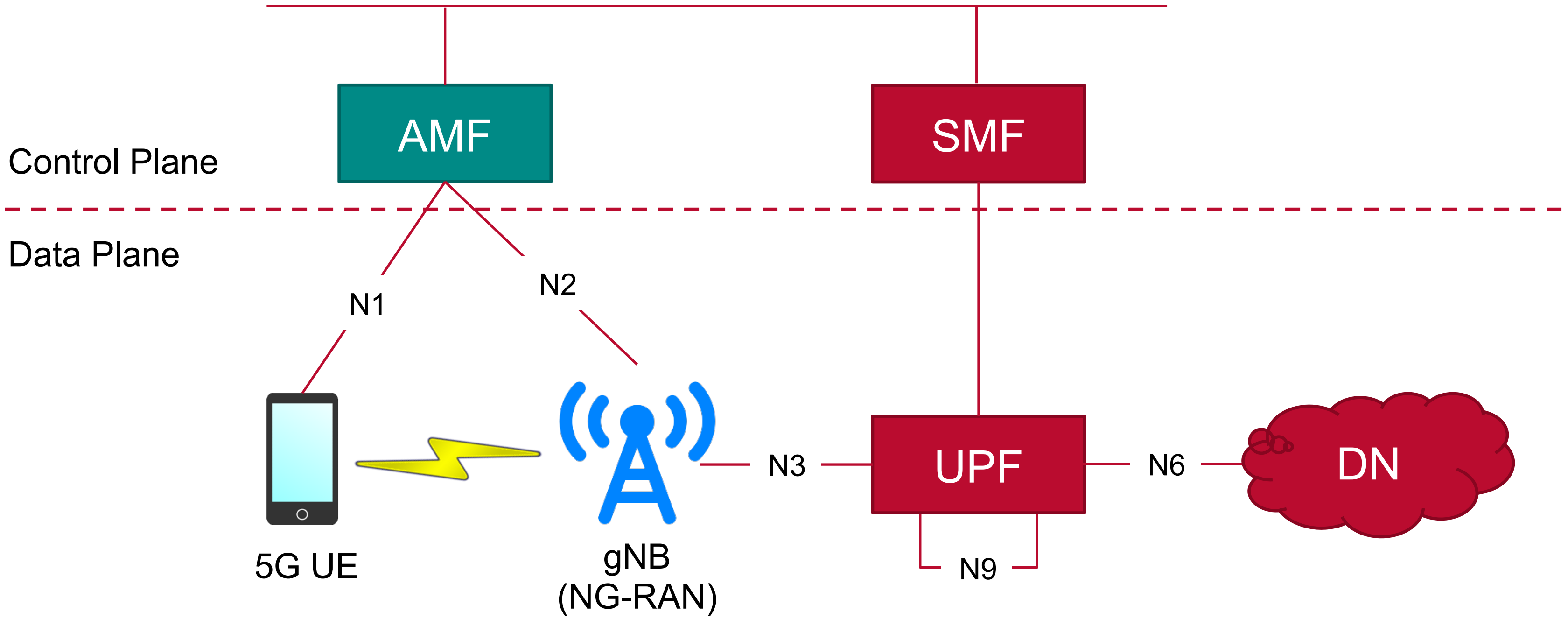
- Session Management e.g. Session Establishment, modify and release, including tunnel maintainance between UPF and AN node.
- UE IP address allocation & management (including optional Authorization) - DHCPv4 (server and client) and DHCPv6 (server and client) functions.
- ARP proxying and / or IPv6 Neighbour Solicitation Proxying functionality for the Ethernet PDUs. The SMF responds to the ARP and / or the IPv6 Neighbour Solicitation Request by providing the MAC address corresponding to the IP address sent in the request.
- Selection and control of UP function, including controlling the UPF to proxy ARP or IPv6 Neighbour Discovery, or to forward all ARP/IPv6 Neighbour Solicitation traffic to the SMF, for Ethernet PDU Sessions.
- Configures traffic steering at UPF to route traffic to proper destination.
- Termination of interfaces towards Policy control functions.
- Lawful intercept (for SM events and interface to LI System).

The Session Management function (SMF)

- Charging data collection and support of charging interfaces.
- Control and coordination of charging data collection at UPF.
- Termination of SM parts of NAS messages.
- Downlink Data Notification.
- Initiator of AN specific SM information, sent via AMF over N2 to AN.
- Determine SSC mode of a session.
- Roaming functionality:
- Handle local enforcement to apply QoS SLAs (VPLMN).
- Charging data collection and charging interface (VPLMN).
- Lawful intercept (in VPLMN for SM events and interface to LI System).
- Support for interaction with external DN for transport of signalling for PDU Session authorization/authentication by external DN.

In addition to the functionalities of the SMF described above, the SMF may include policy related functionalities.

5G NF Operations



Access and Mobility Management function (AMF)

The AMF provides functions similar to (but more extended than) the 4G MME node.

It reassembles all the functions related to the UEs.

The AMF includes the following functionality (some or all may be supported in a single instance):

- Termination of RAN CP interface (N2) and of NAS (N1), NAS ciphering and integrity protection.
- Registration, Connection, Reachability, and Mobility management.
- Lawful intercept (for AMF events and interface to LI System).
- Provide transport for SM messages between UE and SMF.
- Access Authentication and Authorization.
- Provide transport for SMS messages between UE and SMSF.
- Security Anchor Functionality (SEAF – see 3GPP TS 33.501).
- Location Services management for regulatory services.
- Provide transport for Location Services messages.
- EPS Bearer ID allocation for interworking with EPS.
- UE mobility event notification.

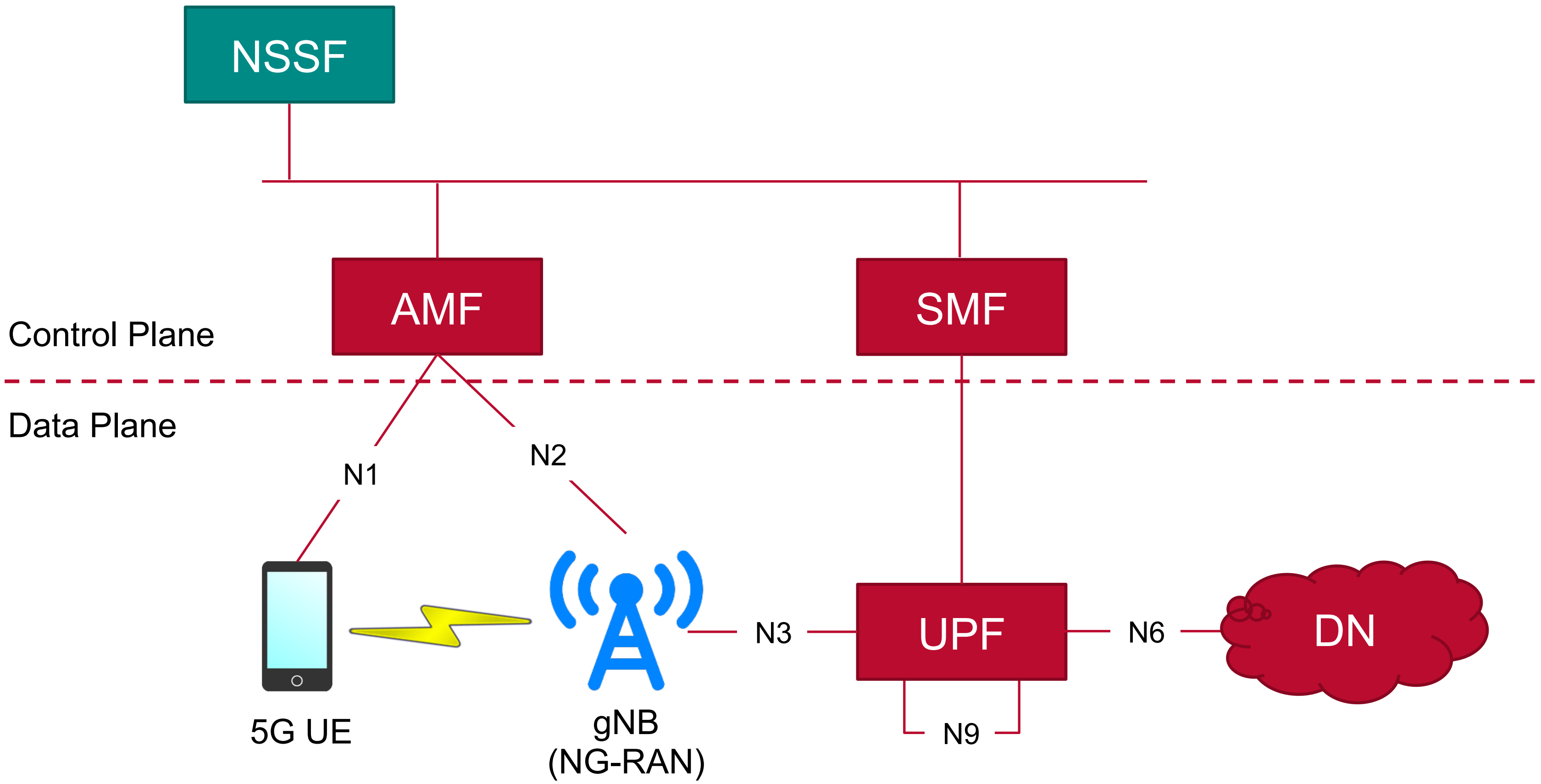
Access and Mobility Management function (AMF)

In addition to the functionalities of the AMF described above, the AMF may include the following functionality to support non-3GPP access networks:

- Support of N2 interface with N3IWF.
- Support of NAS signalling with a UE over N3IWF.
- Support of authentication of UEs connected over N3IWF.
- Management of mobility, authentication, and separate security context state(s) of a UE connected via non-3GPP access or connected via 3GPP and non-3GPP accesses simultaneously.
- Support a co-ordinated RM management context valid over 3GPP and Non 3GPP accesses.
- Support dedicated CM management contexts for the UE for connectivity over non-3GPP access.

In addition to the functionalities of the AMF described above, the AMF may include policy related functionalities.

5G NF Operations

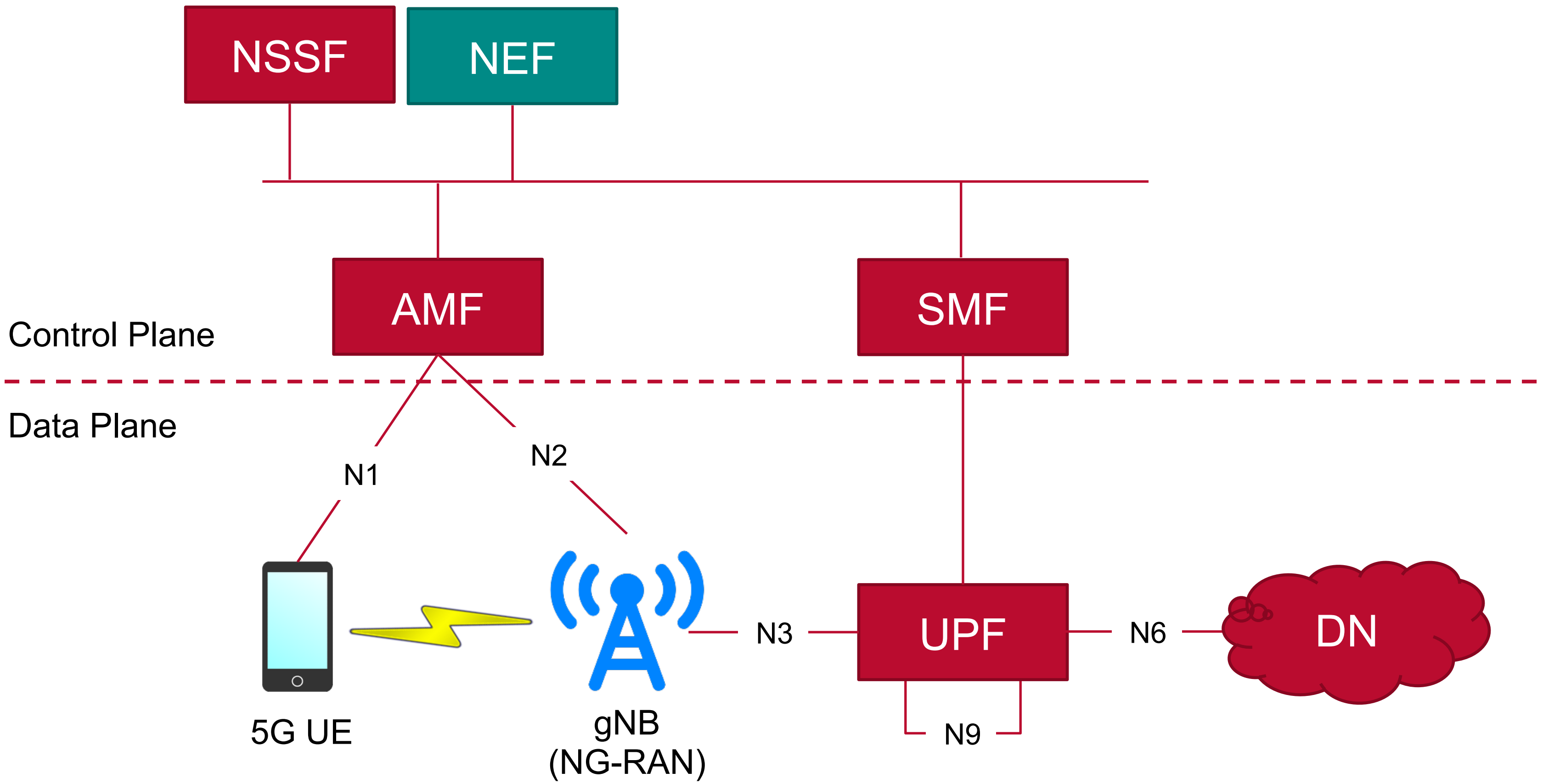


Network Slice Selection Function (NSSF)

The NSSF supports the following functionality:

- Selecting the set of Network Slice instances serving the UE,
- Determining the Allowed NSSAI (Network Slice Selection Assistance Information) and, if needed, the mapping to the Subscribed S-NSSAIs (Single NSSAI),
- Determining the Configured NSSAI and, if needed, the mapping to the Subscribed S-NSSAIs,
- Determining the AMF Set to be used to serve the UE, or, based on configuration, a list of candidate AMF(s), possibly by querying the NRF.

5G NF Operations



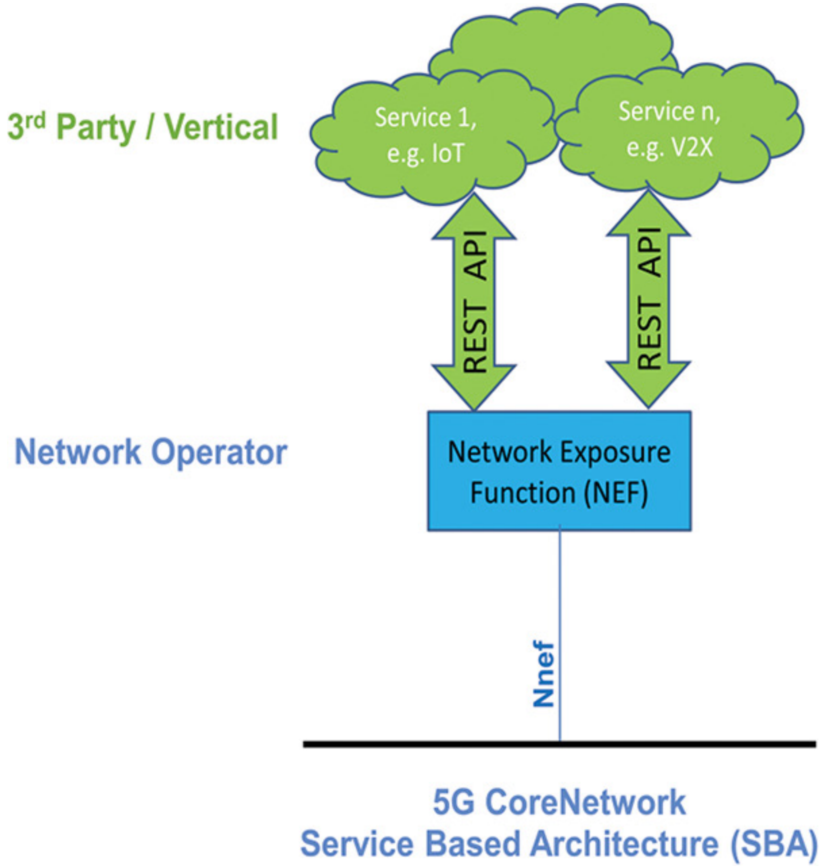
Network Exposure Function (NEF)

Capability exposure is one of the key innovation aspect of the 5G specification.

Capability exposure consists of making 5G Core Network functionalities available to 3rd parties such as service providers and vertical industries outside the operator's domain.

This capability is offered by the Network Exposure Function (NEF).

3GPP decided that 5G service exposure by the NEF should be based on RESTful APIs.



Network Exposure Function (NEF)

The Network Exposure Function (NEF) uses the 5G CAPIF (Common API Framework) as northbound interface.

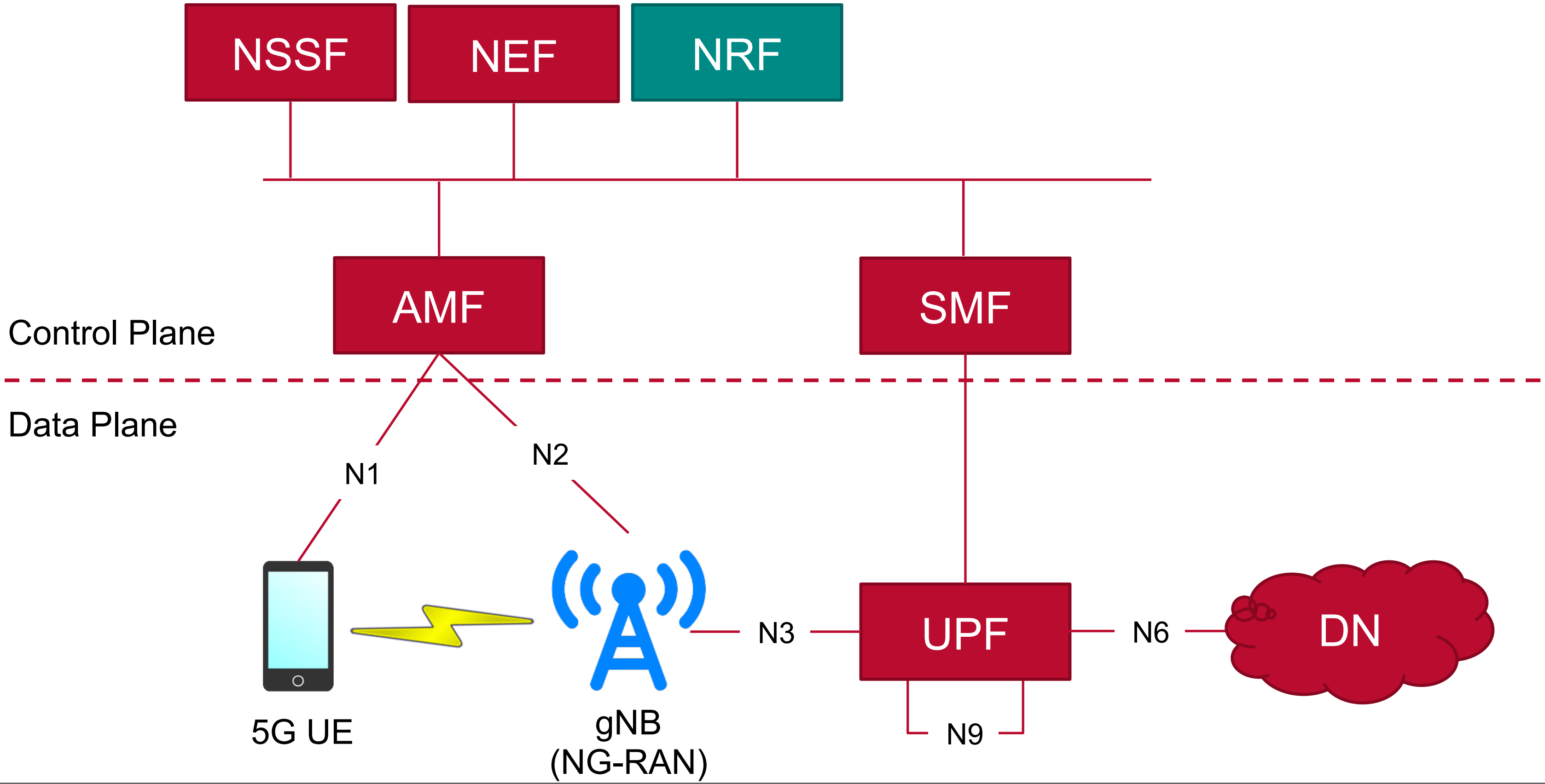
The NEF supports the following independent functionality:

- Exposure of capabilities and events:
  - 3GPP NFs expose capabilities and events to other NFs via NEF.
  - NF exposed capabilities and events may be securely exposed for e.g. 3rd party, Application Functions, Edge Computing.
  - NEF stores/retrieves information as structured data using a standardized interface (Nudr) to the Unified Data Repository (UDR).
- Secure provision of information from external application to 3GPP network:
  - It provides a means for the Application Functions to securely provide information to 3GPP network, e.g. Expected UE Behaviour.
  - In that case the NEF may authenticate and authorize and assist in throttling the Application Functions.

Network Exposure Function (NEF)

- Translation of internal-external information:
  - It translates between information exchanged with the AF and information exchanged with the internal network function.
  - NEF handles masking of network and user sensitive information to external AF's according to the network policy.
  - In detail, NEF:
    - receives information from other network functions (based on exposed capabilities of other network functions).
    - stores the received information as structured data using a standardized interface to a Unified Data Repository (UDR).
    - re-exposes stored data to other network functions and Application Functions, and used for other purposes such as analytics.
  - A specific NEF instance may support one or more of the functionalities described above and consequently an individual NEF may support a subset of the APIs specified for capability exposure.

5G NF Operations



Network Repository Function (NRF)

The Network Repository Function (NRF) supports the following functionality:

- **Supports service discovery function**.
  Receive NF Discovery Request from NF instance, and provides the information of the discovered NF instances (be discovered) to the NF instance.
- **Maintains the NF profile** of available NF instances and their supported services.
  NF profile of NF instance maintained in an NRF includes the following information:
  - NF instance ID, NF type, PLMN ID, Network Slice related Identifier(s), FQDN or IP address of NF, NF capacity information, NF Specific Service authorization information, Names of supported services, Endpoint Address(es) of instance(s) of each supported service, identification of stored data/information, other service parameter, Routing ID part of SUCI, one or more GUAMI(s) in case of AMF, TAI(s) in case of AMF, UDM/UDR/AUSF Group ID applicable for UDM/UDR/AUSF only.

Principles for Network Function and Network Function Service discovery and selection

The NF discovery and NF service discovery enables one NF to discover a set of NF instance(s) for a specific NF service or a target NF type.

Unless the expected NF and NF service information is locally configured on the requester NF, e.g. when the expected NF service or NF is in the same PLMN as the requester NF, the NF and NF service discovery is implemented via the NRF.

In order for the requested NF type or NF service to be discovered via the NRF, the NF instance with its NF service instance(s) need to be registered in the NRF.

Principles for Network Function and Network Function Service discovery and selection

The requester NF initiates a discovery procedure with the NRF by providing the type of the NF or the specific service is attempting to discover.

- The requester NF may also provide other service parameters e.g. slicing related information.

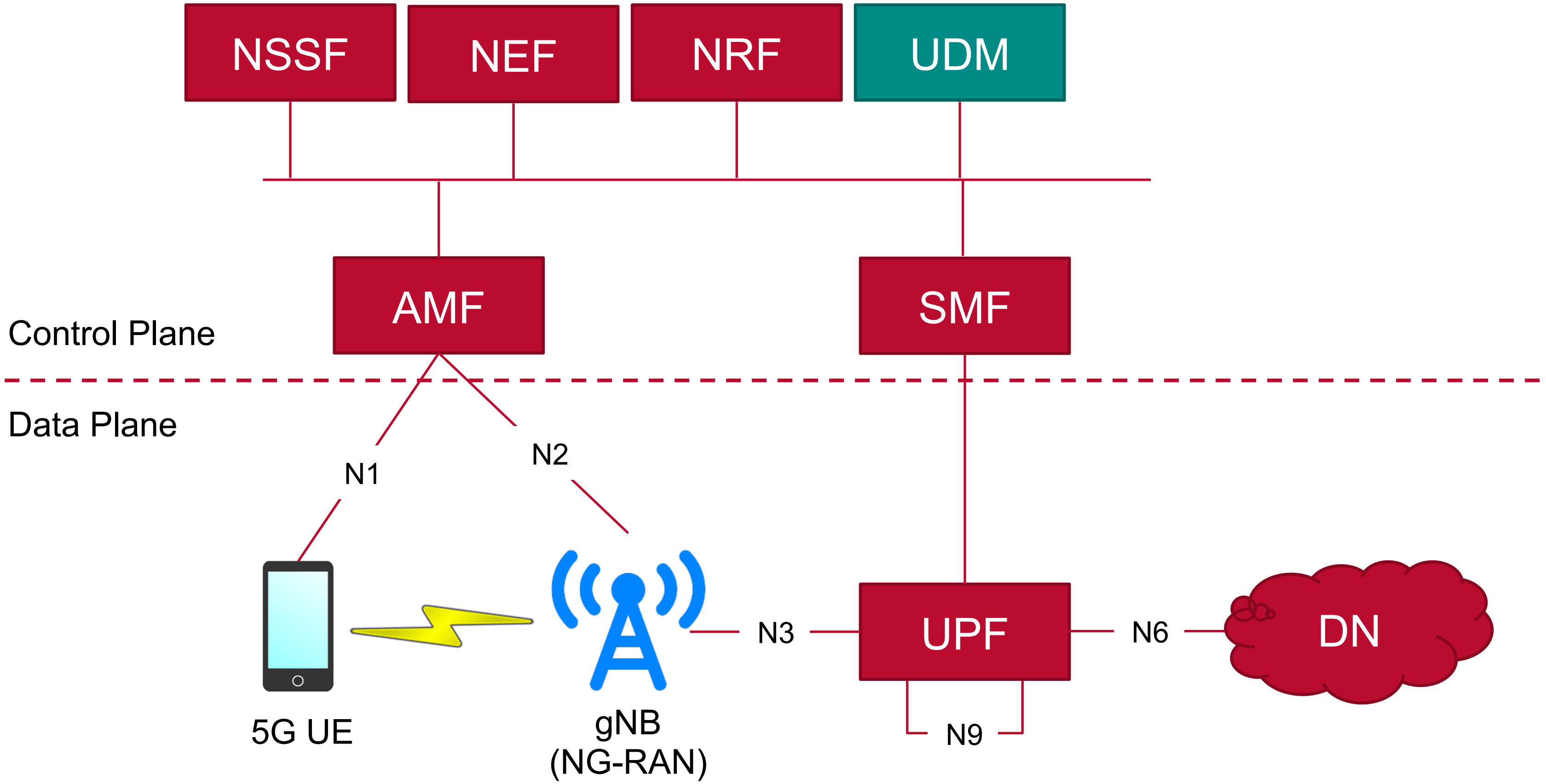
The NRF provides a list of NF instances and NF service instances relevant for the discovery criteria.

The result of the NF discovery procedure is applicable to any subscriber that fulfils same discovery criteria.

The requester NF uses the discovery result to select one specific NF instance or a NF service instance that is able to provide a particular NF Service.

The requester NF may subscribe in the NRF to receive notifications of newly registered/updated/de-registered NF/NF service instances of target NF/NF Service.

5G NF Operations

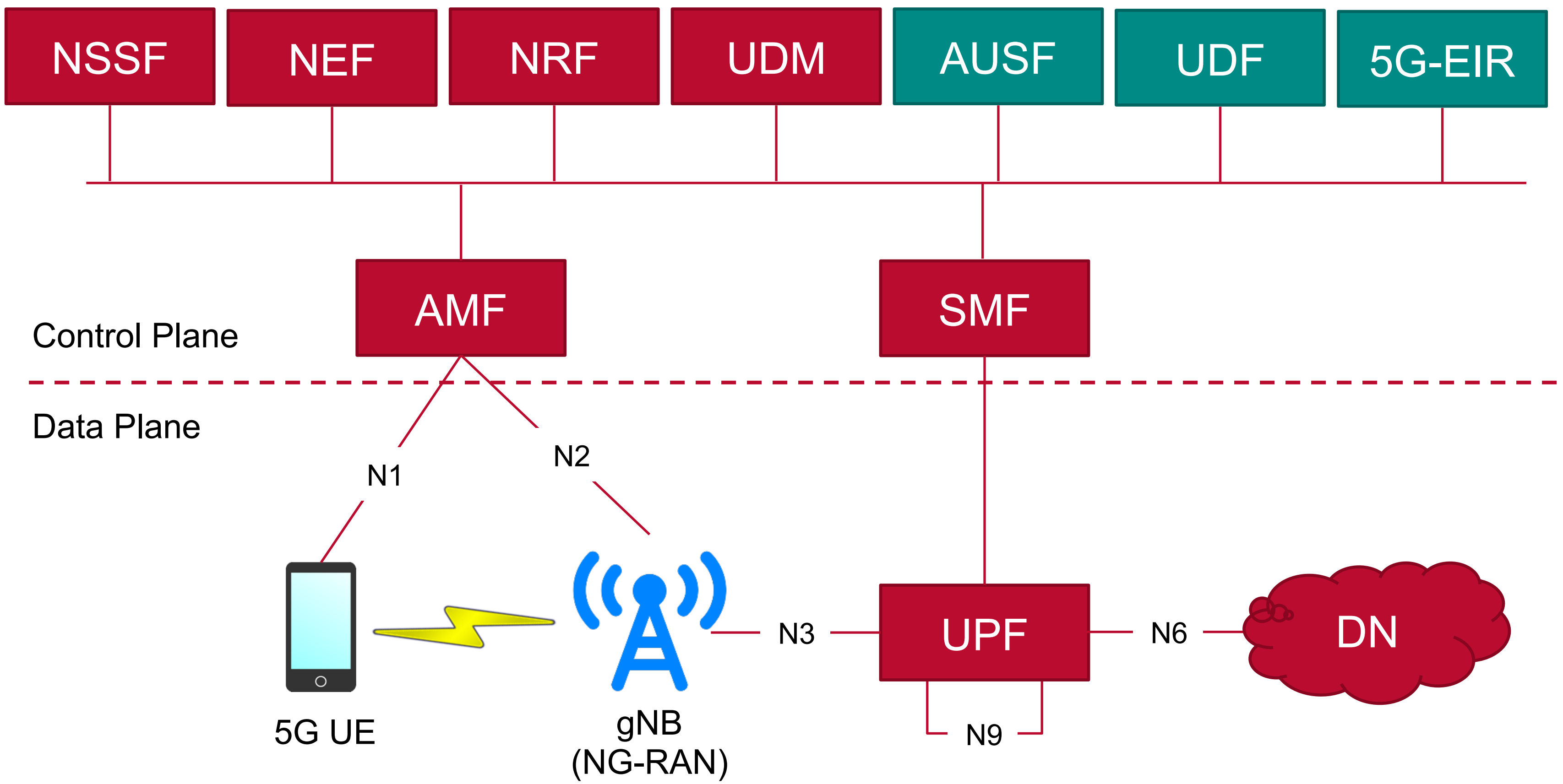


Unified Data Management (UDM)

The Unified Data Management (UDM) includes support for the following functionality:

- Generation of 3GPP AKA Authentication Credentials.
- User Identification Handling.
- Support of de-concealment of privacy-protected subscription identifier (SUCI).
- Access authorization based on subscription data (e.g. roaming restrictions).
- UE's Serving NF Registration Management (e.g. storing serving AMF for UE, etc.).
- Support to service/session continuity.
- MT-SMS delivery support.
- Lawful Intercept Functionality.
- Subscription management.
- SMS management.

5G NF Operations



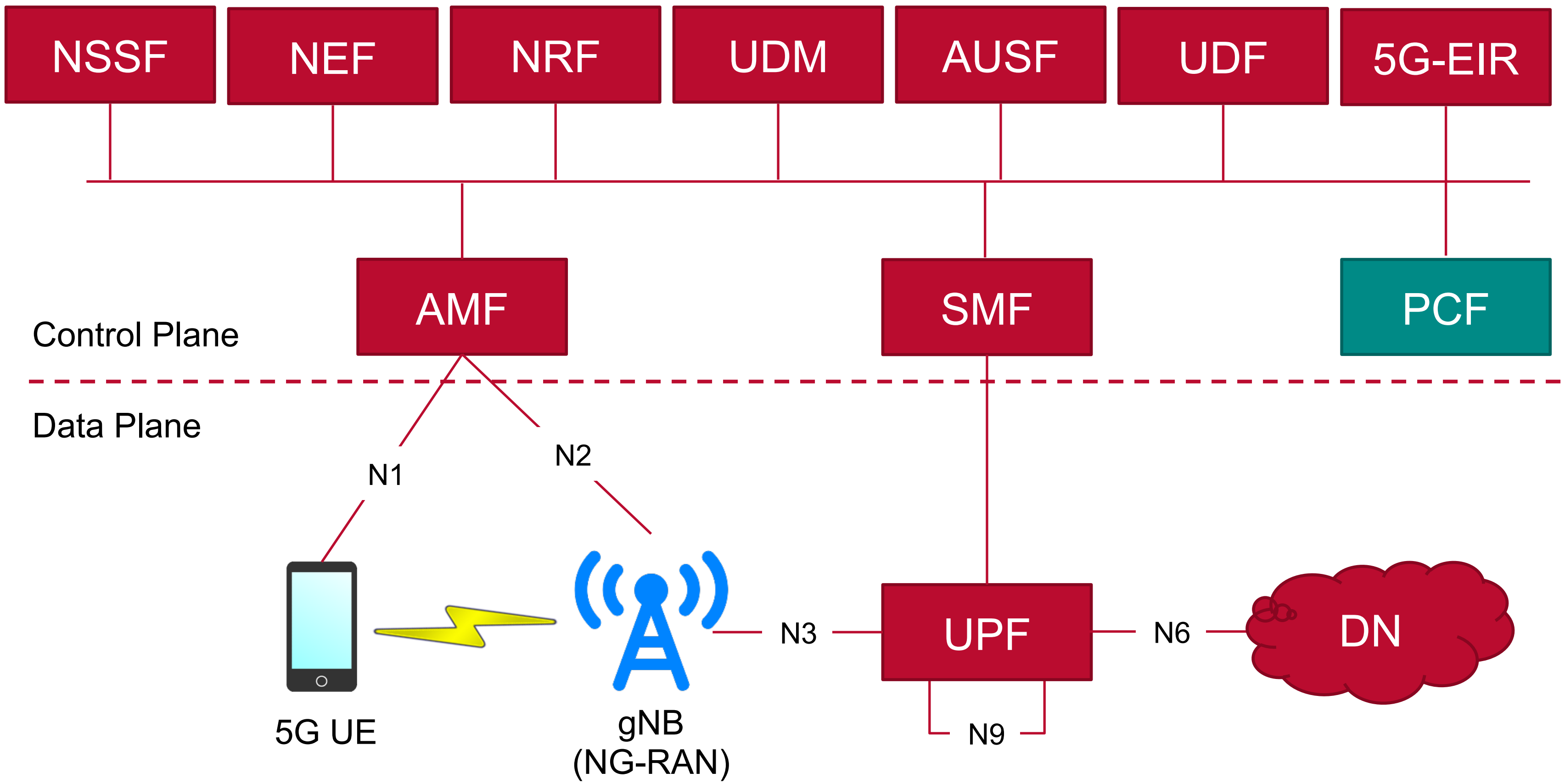
Other NF

The **Authentication Server Function** (**AUSF**) supports the authentication for 3GPP access and untrusted non-3GPP access.

The **Unstructured Data Storage Function** (**UDF**) is an optional function that supports the storage and retrieval of information as unstructured data by any NF.

The **5G Equipment Identity Register** (**5G-EIR**) is an optional network function that supports the status check of the Permanent Equipment Identifier (PEI – e.g. to check that it has not been blacklisted).

5G NF Operations

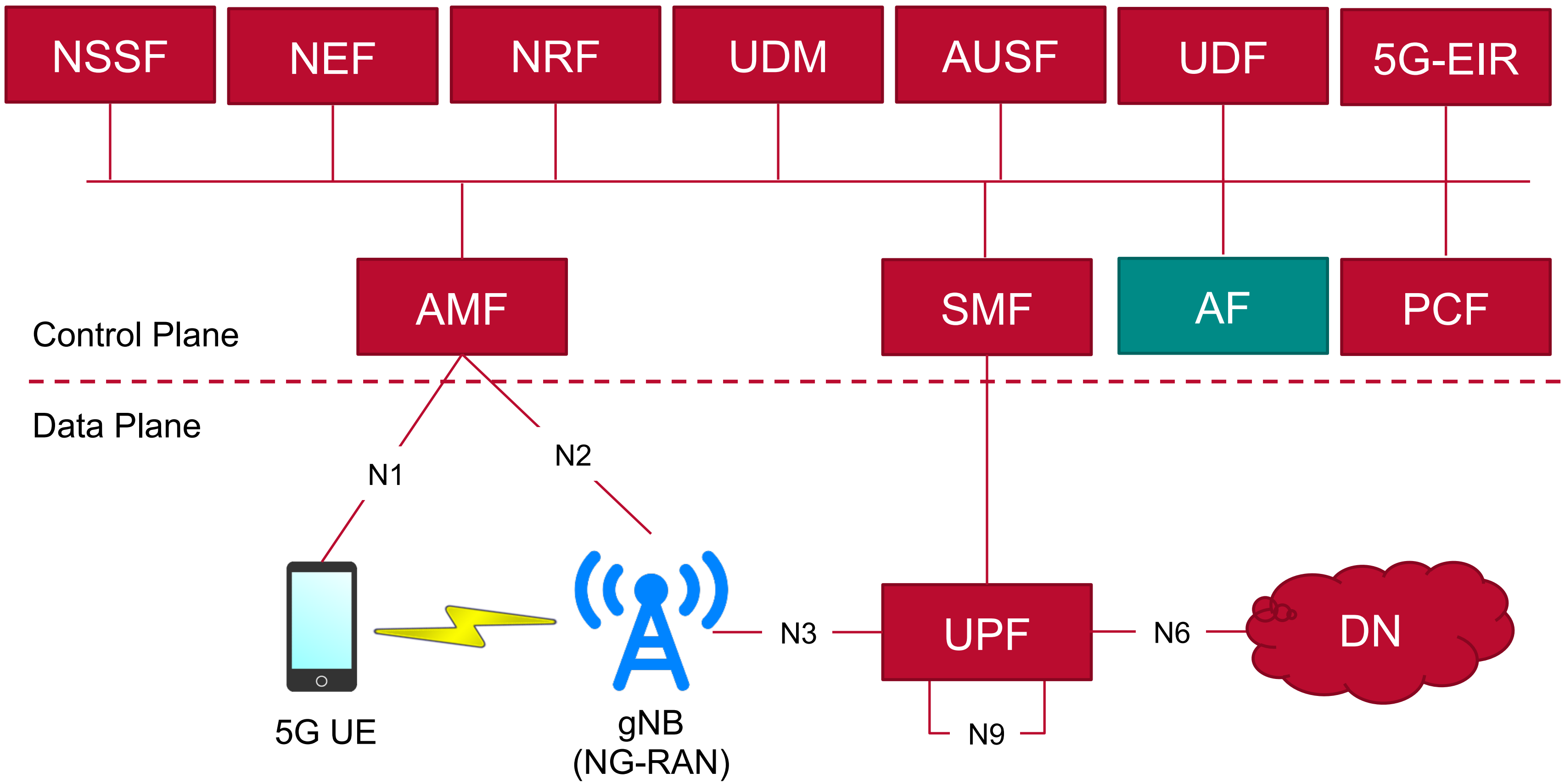


Policy Control Function (PCF)

The Policy Control Function (PCF) includes the following functionality:

- Supports unified policy framework to govern network behaviour.
- Provides policy rules to Control Plane function(s) to enforce them.
- Accesses subscription information relevant for policy decisions in a Unified Data Repository (UDR).

5G NF Operations



Application Function (AF)

The Application Function (AF) interacts with the 3GPP Core Network in order to provide services, for example to support the following:

- Application influence on traffic routing,
- Accessing Network Exposure Function,
- Interacting with the Policy framework for policy control,

Based on operator deployment, Application Functions considered to be trusted by the operator can be allowed to interact directly with relevant Network Functions.

Application Functions not allowed by the operator to access directly the Network Functions shall use the external exposure framework via the NEF to interact with relevant Network Functions.

The functionality and purpose of Application Functions are only defined in this specification with respect to their interaction with the 3GPP Core Network.

Non-3GPP Inter-Working Function (N3IWF)

The functionality of N3IWF in the case of untrusted non-3GPP access includes the following:

- Support of IPsec tunnel establishment with the UE.
- Termination of N2 and N3 interfaces to 5G Core Network for control - plane and user-plane, respectively.
- Relaying uplink and downlink control-plane NAS (N1) signalling between the UE and AMF.
- Handling of N2 signalling from SMF (relayed by AMF) related to PDU Sessions and QoS.
- Establishment of IPsec Security Association (IPsec SA) to support PDU Session traffic.
- Relaying uplink and downlink user-plane packets between the UE and UPF.
  - De-capsulation/ encapsulation of packets for IPSec and N3 tunnelling.
- Enforcing QoS corresponding to N3 packet marking, taking into account QoS requirements associated to such marking received over N2.
- N3 user-plane packet marking in the uplink.
- Local mobility anchor within untrusted non-3GPP access networks using MOBIKE (IETF RFC 4555).
- Supporting AMF selection.

Unified Data Repository (UDR)

The Unified Data Repository (UDR) supports the following functionality:

- Storage and retrieval of subscription data by the UDM.
- Storage and retrieval of policy data by the PCF.
- Storage and retrieval of structured data for exposure.
- Application data (including Packet Flow Descriptions (PFDs) for application detection, AF request information for multiple UEs), by the NEF.

The Unified Data Repository is located in the same PLMN as the NF service consumers storing in and retrieving data from it using Nudr.

- Nudr is an intra-PLMN interface.

SMS Function (SMSF)

The SMSF supports the following functionality to support SMS over NAS:

- SMS management subscription data checking and conducting SMS delivery accordingly.
- SM-RP/SM-CP with the UE.
- Relay the SM from UE toward SMS-GMSC/IWMSC/SMS-Router.
- Relay the SM from SMS-GMSC/IWMSC/SMS-Router toward the UE.
- SMS related CDR.
- Lawful Interception.
- Interaction with AMF and SMS-GMSC for notification procedure that the UE is unavailable for SMS transfer.

Location Management Function (LMF)

The LMF includes the following functionality:

- Supports location determination for a UE.
- Obtains downlink location measurements or a location estimate from the UE.
- Obtains uplink location measurements from the NG RAN.
- Obtains non-UE associated assistance data from the NG RAN.

Security Edge Protection Proxy (SEPP)

The Security Edge Protection Proxy (SEPP) is a non-transparent proxy and supports the following functionality:

- Message filtering and policing on inter-PLMN control plane interfaces
- Topology hiding

The SEPP applies its functionality to every Control Plane message in inter-PLMN signalling, acting as a service relay between the actual Service Producer and the actual Service Consumer.

For both Service Producer and Consumer, the result of the service relaying is equivalent to a direct service interaction.

Every Control Plane message in inter-PLMN signalling between the SEPPs may pass via IPX entities.

Network Data Analytics Function (NWDAF)

NWDAF represents operator managed network analytics logical function.

NWDAF provides slice specific network data analytics to a NF.

NWDAF provides network analytics information (i.e., load level information) to a NF on a network slice instance level and the NWDAF is not required to be aware of the current subscribers using the slice.

NWDAF notifies slice specific network status analytic information to the NFs that are subscribed to it.

NF may collect directly slice specific network status analytic information from NWDAF.

This information is not subscriber specific.

In Release 15.0 of the 3GPP specification, both PCF and NSSF are consumers of network analytics.

- The PCF may use that data in its policy decisions.
- NSSF may use the load level information provided by NWDAF for slice selection.

Application Function (AF)

Application Function(s) can be internal or external to the 5GS Providers.

Their nature is not defined because they can correspond to:

- Over-The-Top systems
- Vertical Applications (i.e., edge computing)
- Etc.

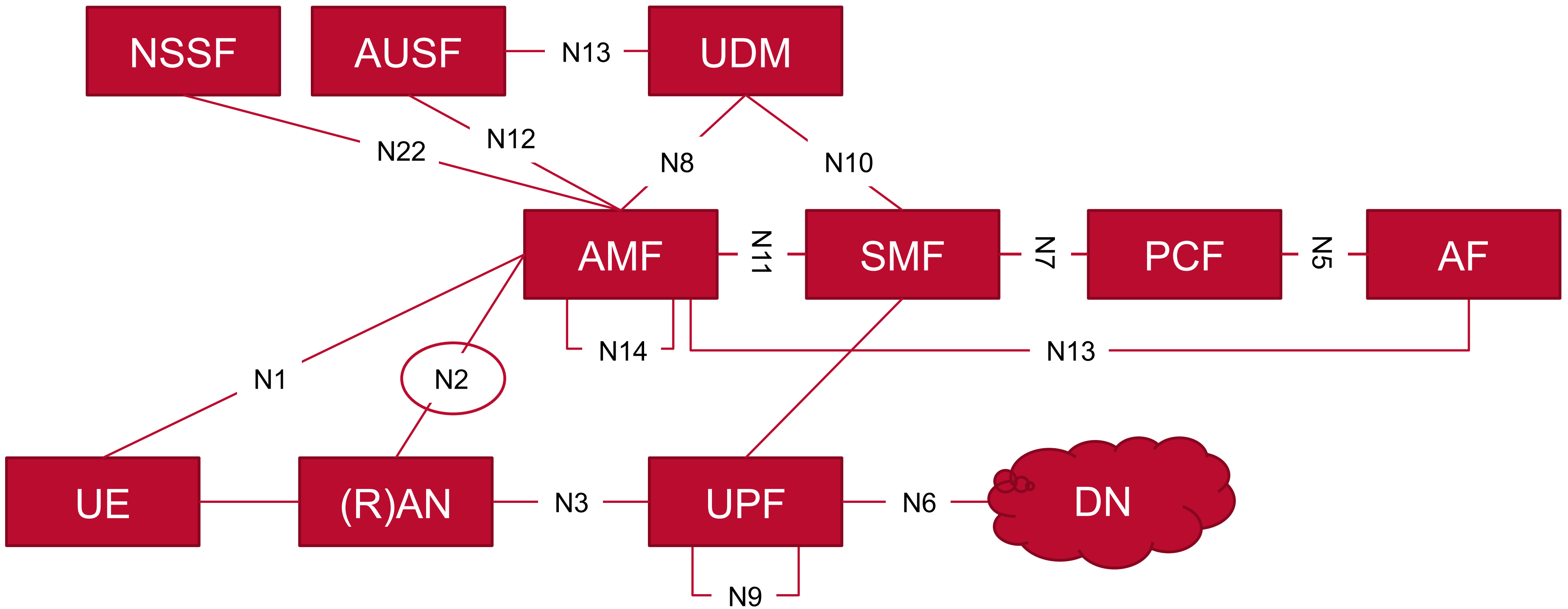
External AF(s) are meant to adopt CAPIF to connectect with NEF.

Application Function (AF)

Information element contained in AF request

Information Name	Applicable for PCF or NEF	Applicable for NEF only	Category
Traffic Description	Defines the target traffic to be influenced, represented by the combination of DNN and optionally S-NSSAI, and application identifier or traffic filtering information.	The target traffic can be represented by AF-Service-Identifier, instead of combination of DNN and optionally S-NSSAI.	Mandatory
Potential Locations of Applications	Indicates potential locations of applications, represented by a list of DNAI(s).	The potential locations of applications can be represented by AF-Service-Identifier.	Conditional (NOTE 1)
Target UE Identifier(s)	Indicates the UE(s) that the request is targeting, i.e. an individual UE, a group of UE represented by Internal Group Identifier, or any UE accessing the combination of DNN, S-NSSAI and DNAI(s).	GPSI can be applied to identify the individual UE, or External Group Identifier can be applied to identify a group of UE.	Mandatory
Spatial Validity Condition	Indicates that the request applies only to the traffic of UE(s) located in the specified location, represented by areas of validity.	The specified location can be represented by a list of geographic zone identifier(s).	Optional
AF transaction identifier	The AF transaction identifier refers to the AF request.	N/A	Mandatory
Traffic Routing requirements	N6 traffic routing information corresponding to each DNAI.	N/A	Optional
Application Relocation Possibility	Indicates whether an application can be relocated once a location of the application is selected by the 5GC.	N/A	Optional
Temporal Validity Condition	Time interval(s) or duration(s).	N/A	Optional
Notification Type	Indicates whether the type of AF subscription to notification is for early notification and/or for late notification.	N/A	Optional

Control Plane Protocol Stacks



The N2 Interface

The N2 Interface is devoted to transport control-plane messages between the 5G AN and the 5G Core.

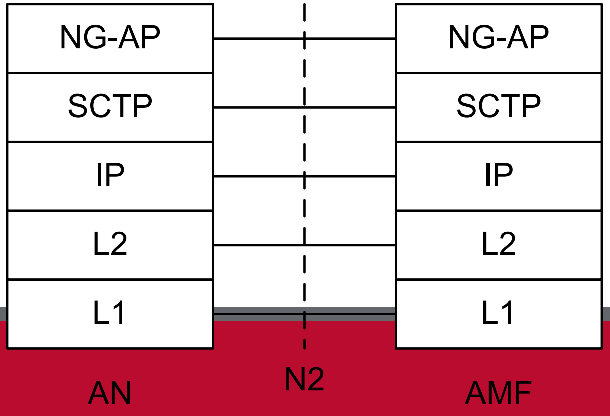
It supports the following procedures:

- Procedures related with ***N2 Interface Management*** and that are not related to an individual UE, such as for Configuration or Reset of the N2 interface.
- Procedures related with an ***individual UE***:
  - **NAS Transport**: These procedures may correspond to messages that for UL NAS transport carry some access dependent information such as User Location Information.
  - **UE context management**: The corresponding messages may carry:
    - some information only on some access (such as Handover Restriction List).
    - some information (related e.g. with N3 addressing and with QoS requirements) that is to be transparently forwarded by AMF between the 5G-AN and the SMF.
  - **PDU Sessions**: These procedures may correspond to messages that carry information (related e.g. with N3 addressing and with QoS requirements) that is to be transparently forwarded by AMF between the 5G-AN and the SMF.
  - **Hand-Over management** (for 3GPP access only).

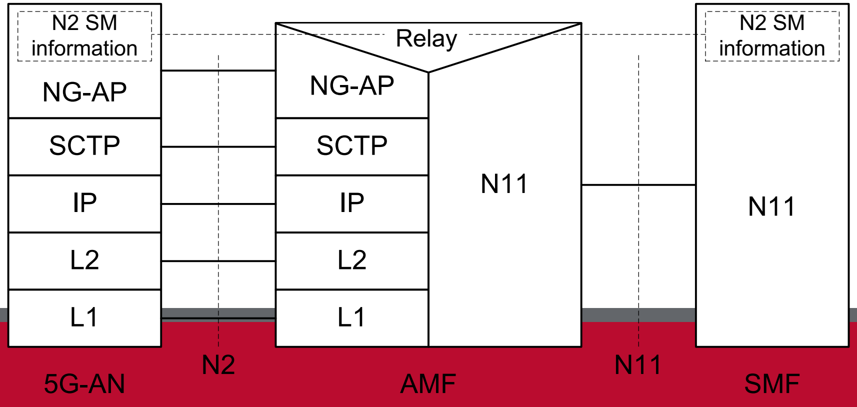
Control Plane Protocol Stacks

The Control Plane interface between the 5G-AN and the 5G Core supports:

- The connection of multiple different kinds of 5G-AN (e.g. 3GPP RAN, N3IWF for Un-trusted access to 5GC) to the 5CG via an unique Control Plane protocol:
  - A single NGAP protocol is used for both the 3GPP access and non-3GPP access;
  - There is a unique N2 termination point in AMF per access for a given UE regardless of the number (possibly zero) of PDU Sessions of the UE;
- The decoupling between AMF and other functions such as SMF that may need to control the services supported by 5G-AN(s) (e.g. control of the UP resources in the 5G-AN for a PDU Session).
- NGAP may support information that the AMF is just responsible to relay between the 5G-AN and the SMF.
- The information can be referred as N2 SM information, and it is exchanged between the SMF and the 5G-AN transparently to the AMF.

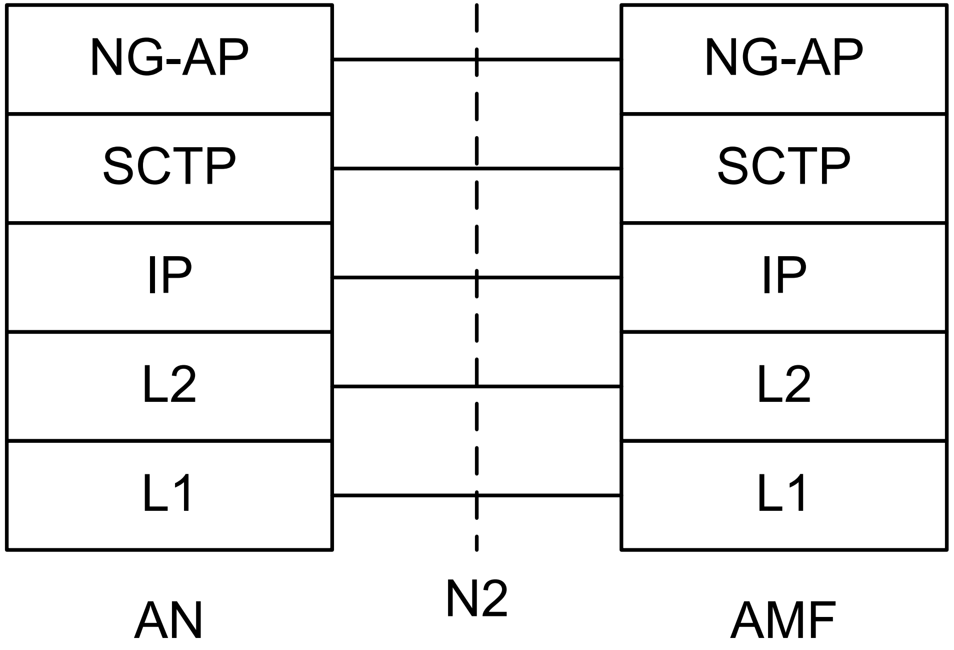


Control Plane between the 5G-AN and the AMF

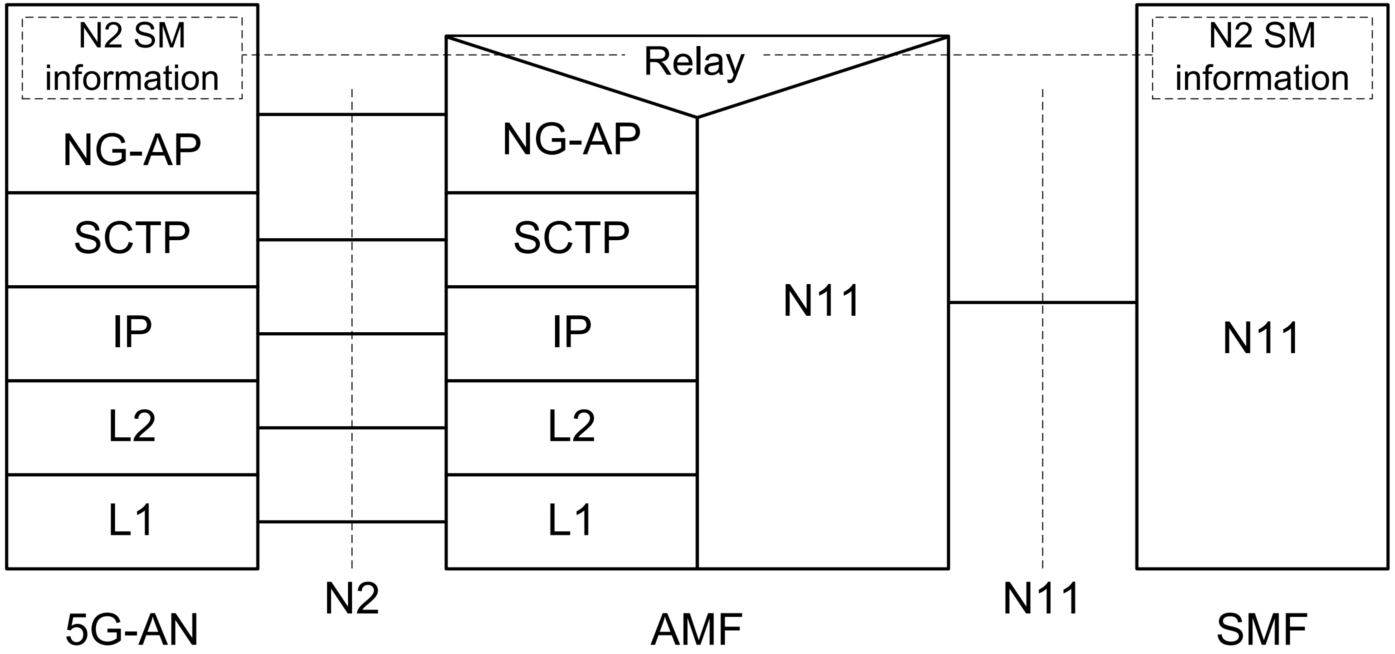


Control Plane between the AN and the SMF

Control Plane Protocol Stacks



Control Plane between the 5G-AN and the AMF



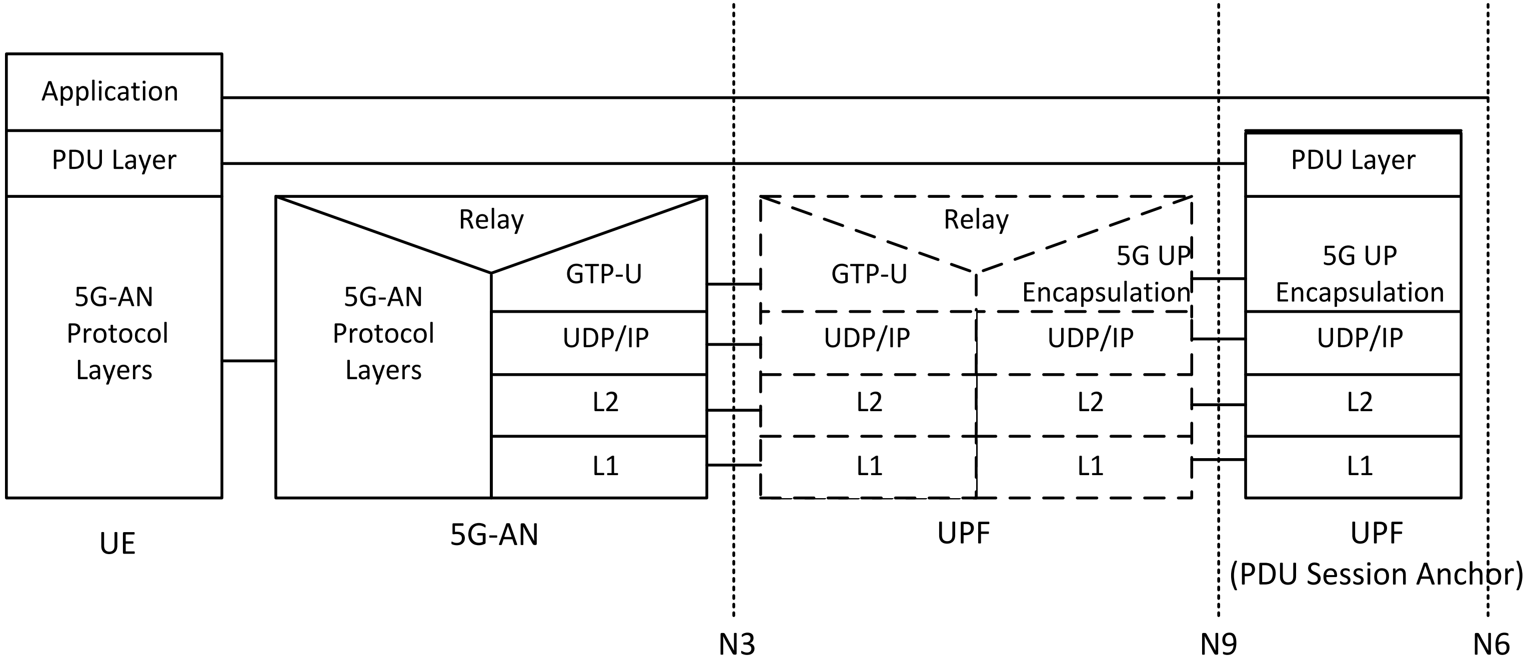
Control Plane between the AN and the SMF

USER Plane Protocol Stacks

PDU layer: This layer corresponds to the PDU carried between the UE and the DN over the PDU Session. A PDU Session Type can be IPv4, IPv6, Ethernet, etc.

GPRS Tunnelling Protocol for the user plane (GTP-U): This protocol supports multiplexing traffic of different PDU Sessions (possibly corresponding to different PDU Session Types) by tunnelling user data over N3 (i.e. between the 5G-AN node and the UPF) in the backbone network. GTP shall encapsulate all end user PDUs. It provides encapsulation on a per PDU Session level.

5G Encapsulation: This layer supports multiplexing traffic of different PDU Sessions (possibly corresponding to different PDU Session Types) over N9 (i.e. between different UPF of the 5GC). It provides encapsulation on a per PDU Session level.



The 5G QoS Model

The 3GPP 5G system architecture defined a new QoS model.

The new model enables differentiated data services to support diverse application requirements while using radio resources efficiently.

The new model adopts a Flow based QoS with a much higher level of granularity than LTE, which is currently limited to the bearer service concept.

At a glance:

- IP Flows are classified and mapped onto QoS Flows/ Service Data Flow (SDF) by means of **SDF templates**.
- A **Service Data Flow** (**SDF**) **filter** is a set of packet flow header parameter values used to identify one or more of the packet flows that constitute an SDF.
- QoS Flows are mapped onto one or more radio bearers, and managed accordingly by UPFs and UEs

The 5G QoS Model

The 5G QoS model:

- is based on QoS Flows.
- supports both QoS Flows that require guaranteed flow bit rate (GBR QoS Flows) and QoS Flows that do not require guaranteed flow bit rate (Non-GBR QoS Flows).
- also supports Reflective QoS.

The QoS Flow is the finest granularity of QoS differentiation in the PDU Session.

A QoS Flow ID (QFI) is used to identify a QoS Flow in the 5G System.

User Plane traffic with the same QFI within a PDU Session receives the same traffic forwarding treatment (e.g. scheduling, admission threshold).

The QFI is carried in an encapsulation header on N3 (and N9) i.e. without any changes to the e2e packet header.

Within the 5GS, a QoS Flow is controlled by the SMF and may be pre-configured, or established via the PDU Session Establishment procedure or the PDU Session Modification procedure.

5G QoS Flow

Any QoS Flow is characterised by:

- **A QoS profile** provided by the SMF to the AN via the AMF over the N2 reference point or preconfigured in the AN;
- **One or more QoS rule(s)** which can be provided by the SMF to the UE via the AMF over the N1 reference point and/or derived by the UE by applying Reflective QoS control; and
- **One or more UL and DL Packet Detection Rule(s)** (i.e., SDF filter) provided by the SMF to the UPF.

Within the 5GS, a Non-GBR QoS Flow associated with the default QoS rule is required to be established for a PDU Session and remains established throughout the lifetime of the PDU Session.

The above QoS Flow provides the UE with connectivity throughout the lifetime of the PDU Session.

- Possible interworking with EPS motivates the restriction of this QoS Flow to be of type Non-GBR.

5G QoS PROFILE

The QoS profile of a QoS Flow contains :

- A 5G QoS Identifier (5QI);
- An Allocation and Retention Priority (ARP).
- For each Non-GBR QoS Flow only, the QoS profile may also include the QoS parameter:
  - Reflective QoS Attribute (RQA).
- For each GBR QoS Flow only, the QoS profile shall also include the QoS parameters:
  - Guaranteed Flow Bit Rate (GFBR) - UL and DL;
  - Maximum Flow Bit Rate (MFBR) - UL and DL.
- In the case of a GBR QoS Flow only, the QoS parameters may also include:
  - Notification control.
  - Maximum Packet Loss Rate - UL and DL.

5G QoS Rules

The UE performs the classification and marking of UL User plane traffic, i.e. the association of UL traffic to QoS Flows, based on QoS rules.

These QoS rules may be explicitly provided to the UE (i.e. explicitly signalled QoS rules using the PDU Session Establishment/Modification procedure), pre-configured in the UE or implicitly derived by UE by applying Reflective QoS.

A QoS rule contains:

- the **QFI** of the associated QoS Flow;
- a **Packet Filter Set**;
- a **precedence value**.

Additionally, for a dynamically assigned QFI, the QoS rule(s) and the QoS Flow level QoS parameters (e.g. 5QI, GFBR, MFBR, Averaging Window) are signalled to the UE on per QoS Flow basis.

An explicitly signalled QoS rule contains a QoS rule identifier which is unique within the PDU Session and is generated by SMF.

A default QoS rule is required to be sent to the UE for every PDU Session establishment and it is associated with a QoS Flow.

5G QoS flow mapping

The SMF performs the binding of SDFs to QoS Flows based on the QoS and service requirements.

The SMF assigns the QFI for a new QoS Flow and derives its QoS profile, corresponding UPF instructions and QoS Rule(s) from the PCC rules and other information provided by the PCF.

When applicable, the SMF provides the following information to the (R)AN:

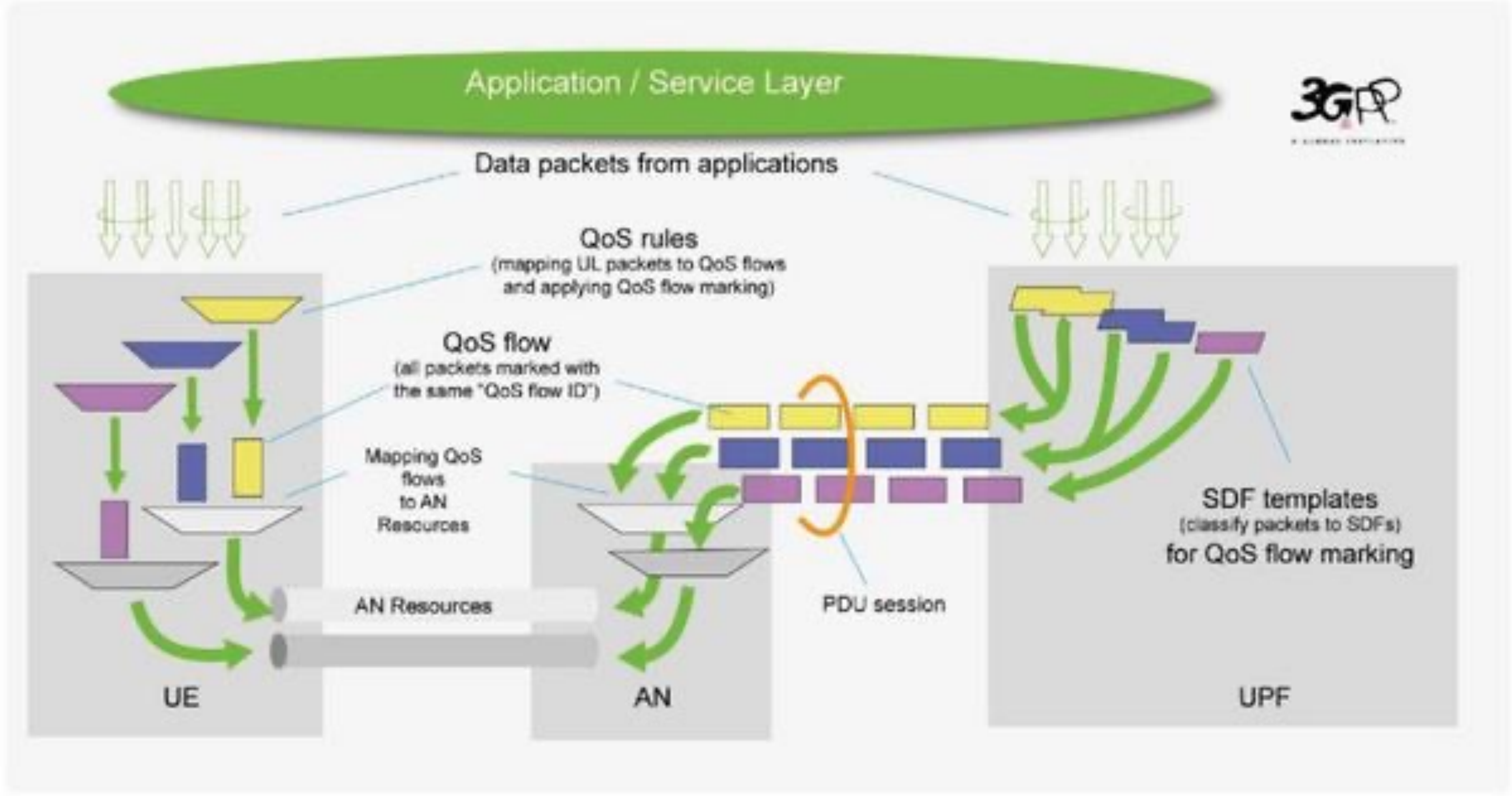
- QFI;
- QoS profile;

The SMF provides the following information to the UPF enabling classification, bandwidth enforcement and marking of User Plane traffic:

- a DL PDR containing the DL Packet Filter Set of the SDF template and an UL PDR containing the UL Packet Filter Set of the SDF template;
- the PDR precedence value for both PDRs is set to the precedence value of the PCC rule;
- QoS related information;

For each SDF, the SMF generates an explicitly signalled QoS rule.

The 5G QoS Model



Standardized 5QI to QoS characteristics mapping

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65		7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75		25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6		60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive
9		90					video, etc.)
69		5	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
81	Delay Critical GBR	11	5 ms	10^{-5}	160 B	2000 ms	Remote control
82		12	10 ms	10^{-5}	320 B	2000 ms	Intelligent transport systems
83		13	20 ms	10^{-5}	640 B	2000 ms	Intelligent Transport Systems
84		19	10 ms	10^{-4}	255 B	2000 ms	Discrete Automation
85		22	10 ms	10^{-4}	1358 B	2000 ms	Discrete Automation